

ML04847

NAVAL SUBMARINE SUPPORT FACILITY



5 0670 01012410 4

USAARL Report No. 93-13



**United States Army
Aeromedical Research Laboratory**

Fort Rucker, Alabama 36362-5292

ADA 262957



**User's Manual
for BRNSIM/BURNSIM:
A Burn Hazard Assessment Model**

ARMSTRONG

LABORATORY

By

F. S. Knox, III
Dena Bonetti
Chris Perry

Escape and Impact Branch
Biodynamics and Biocommunications Division

February 1993

20050718028

Approved for public release; distribution unlimited.

**AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573**

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Animal use

In conducting the research described in this report, the investigators adhered to the Guide for Laboratory Animal Facilities and Care, as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences-National Research Council.

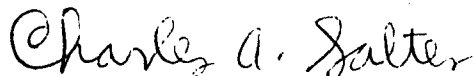
Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

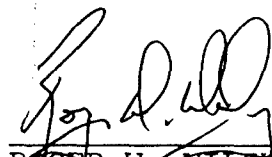
Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Reviewed:

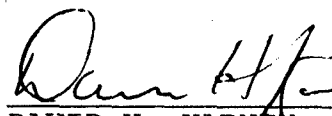


CHARLES A. SALTER
LTC, MC
Director, Biomedical Applications
Research Division



ROGER W. WILEY, O. D., Ph.D.
Chairman, Scientific
Review Committee

Released for publication:



DAVID H. KARNEY
Colonel, MC, SFS
Commanding

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 1993 February		3. REPORT TYPE AND DATES COVERED Interim - 1980-1992
4. TITLE AND SUBTITLE User's Manual for BRNSIM/BURNSIM: A Burn Hazard Assessment Model			5. FUNDING NUMBERS PE - 62202A PR - 7231 TA - 723124 WU - 72312403	
6. AUTHOR(S) F.S. Knox III Dena Bonetti Chris Perry				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Crew Systems Directorate U.S. Army Aeromedical Armstrong Laboratory Research Laboratory Human Systems Center Box 620577 Wright-Patterson AFB OH 45433-6573 Fort Rucker AL 36362 -0577			8. PERFORMING ORGANIZATION REPORT NUMBER USAARL Report No. 93-13	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research & Development Command Fort Detrick MD 27514-5000 Human Systems Center Defense Nuclear Agency Brooks AFB TX 78235-5000 RAAP Washington DC 20305-1000			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES This report is a product of a program supported by both the U.S. Army Medical R&D Command through its U.S. Army Aeromedical Research Laboratory at Fort Rucker) and the U.S. Air Force (Materials Laboratory, Life Support SPO, and Armstrong Laboratory) from 1970-1992. The senior author has been the principal investigator throughout.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) BURNSIM is an interactive computer model which runs on DEC minicomputers (PDP 11 and VAX), Macintosh and IBM compatible PCs. The model is based on the work of Moritz and Henriques at Harvard, the Surgery Department at University of Rochester; Alice Stoll at Naval Air Development Center and Knox et al. at the U.S. Army Aeromedical Research Laboratory. Its development has been funded by the U.S. Army, U.S. Air Force, and Dr. Knox. The model predicts time to pain and burn depth when bare skin is exposed to any arbitrary time history of heat flux. It predicts burn depth with reasonable accuracy for pig and human skin. A software module to include clothing between the thermal source and the skin has been developed but not integrated with BURNSIM and has not been validated. By using sensors to measure heat flux behind fabric it has been possible to use BURNSIM to evaluate the insulating effect of clothing. BURNSIM has been used in the last several years to assess the burn hazard associated with rocket plumes in side-by-side ejection seats, shoulder launched weapons, nuclear flash and live fire. This manual provides information on model development, its installation and use on a PC.				
14. SUBJECT TERMS ✓ Burns ✓ Computer model ✓ Thermal protection ✓ Burn hazard prediction			15. NUMBER OF PAGES 70	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

Acknowledgments

The senior author wishes to express his gratitude to the many colleagues who have contributed to the development of BURNSIM. Drs. Stanley C. Knapp, Thomas L. Wachtel, and Chap McCahan have worked on the project from the beginning in 1970 when we were all stationed at the U.S. Army Aeromedical Research Laboratory. Dr. Knapp had started the project to study postcrash fires with funding from various sources including the U.S. Army Medical Research and Development Command and the USAF Life Support Systems Program Office at Wright-Patterson Air Force Base. Dr. Cal Lum helped during the data collection phase in 1972. Dr. Daniel D. Reneau and his graduate student, Nelson O'Young, contributed the basic section of code to calculate the conductive heat transfer. Randy Nockton and Chet Ellis contributed additional software development including tape reading routines, statistical analysis programs and a database to manage the data. Dr. Charles Yuell, a pathologist at the Rochester School of Medicine, helped clarify the burn depth grading scheme and even found some of the original porcine skin samples from earlier burn studies at Rochester. Mr. Chris Perry and CPT Dena Bonetti have worked with BURNSIM for the past 3 years at the Armstrong Laboratory and have contributed to the current effort supported by the Defense Nuclear Agency. Part of this effort is the PC version of BURNSIM for which CPT Dena Bonetti is largely responsible. Funding for this effort has come from the U.S. Army Medical R&D Command, Defense Nuclear Agency, and the U.S. Air Force without which BURNSIM would not have been developed.

Table of contents

Background	1
Model description	3
Getting started	3
Helpful hints	19
References	21
Bibliography	23
Appendix A	33
Appendix B	46
Appendix C	66

List of illustrations

Figure 1. Tissue damage integral indicative of the blister endpoint .	2
Figure 2. Skin representation	4
Figure 3. Skin temperatures at first six nodes calculated with Burnsim for Stoll's data	19

Background

BRNSIM (or BURNSIM as it is now called) is a computer model which allows the user to convert heat flux incident to bare skin to a predicted burn depth. The requirement for such a model arose when there was a need to quantify the thermal protective properties of new flight suits. Techniques employed in the 1960s and very early 1970s did not predict the full range of burns from no burn to full thickness and failed to take into account both initial conditions of the skin and its adaptive behavior when heated.

Since the late 1960s, the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, has been involved in quantifying the burn hazard associated with post crash fires and the protective capability of flight clothing¹. USAARL staff (including the author) conducted a number of field studies using burning helicopters to establish the severity and time course of post crash fires (Knapp and Knox, 1982). They also 1) built and used two fire simulators to study the effect of simulated postcrash fires on pigs as an analog for man (Knox et al., 1978b), 2) placed fabrics between the fire and the pigs to study their protective capability (Knox et al., 1980), 3) assembled a large porcine (pig) burn database using this bioassay method (Knox, 1979a), and 4) developed the model, BRNSIM, to decrease the workload associated with using the bioassay method to assess fabric protective capabilities (Knox, 1979b).

The starting point for building BRNSIM (short for burn simulation) was the work of Alice Stoll who based her model on Moritz and Henriques' damage integral (Henriques, 1947). She had collected data from human volunteers on the time/heat flux relationships resulting in threshold transepidermal necrosis. This burn is represented by minor blister formation. To explain her results she added a consideration of damage occurring during cooling as well as during the heating phase (Figure 1). Stoll chose the constants (Stoll and Greene, 1959) in her model to fit her human data on threshold burns; more severe burns were not at first considered. Later Weaver and Stoll (1969) proposed an extension of Stoll's first model to include more severe burns without experimental basis.

The first model to come out of the USAARL program was that of Art Takata of IITRI (Takata, 1974) who worked for USAARL as a contractor. He started with Stoll's approach and added water boiling as a way of handling blister formation. He then adjusted the constants ($P, \Delta E$) (see equation (7) in Appendix A) to more accurately predict USAARL's data on more severe porcine burns.

¹The development of this model and the work upon which it is based has been funded by U.S. Army Medical Research & Development Command, Fort Detrick; U.S. Air Force Life Support Systems Program Office and Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio; Defense Nuclear Agency, Washington D.C., and as a personal project by the primary author.

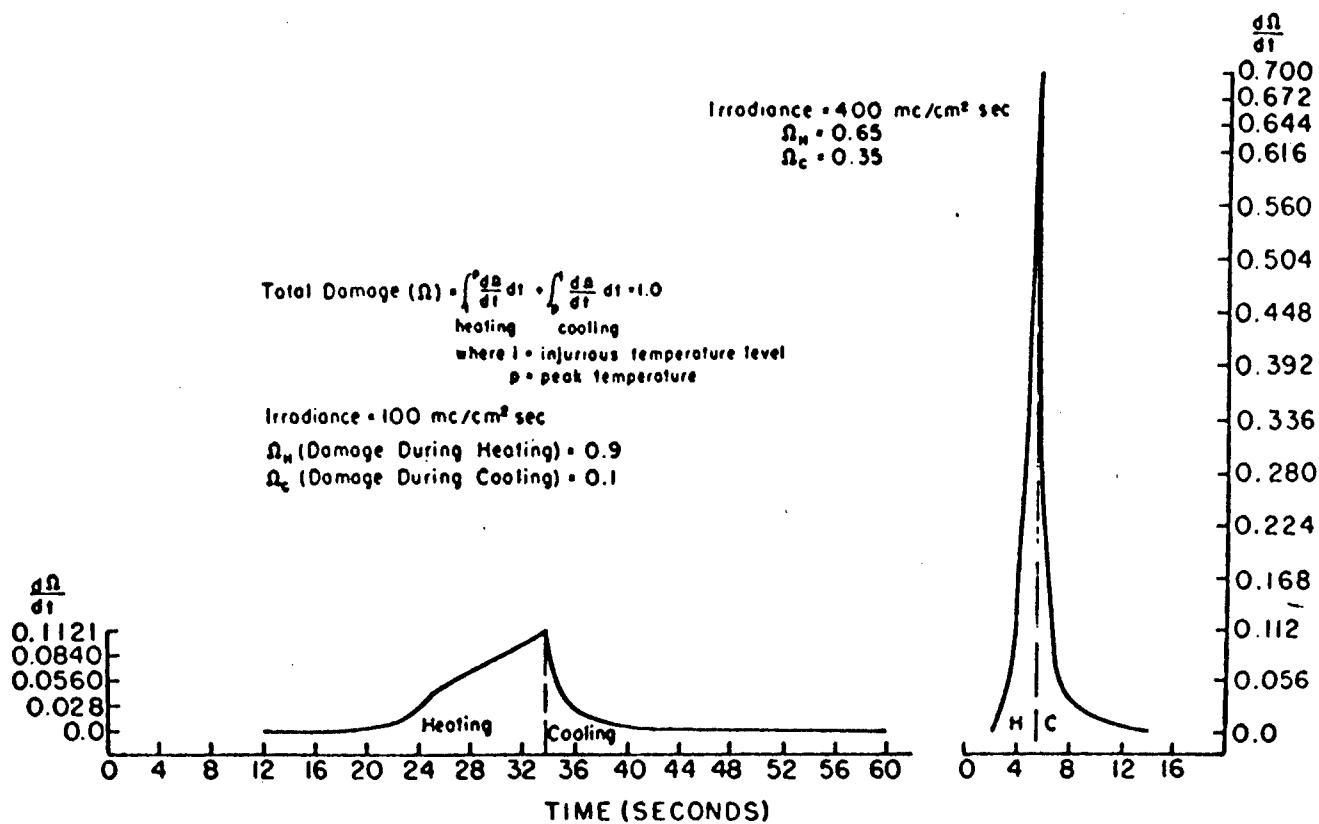


Figure 1. Tissue damage integral indicative of the blister endpoint
 (Stoll and Chianta, 1971)

The current BURNSIM model builds on these earlier efforts (Henriques, 1947; Weaver and Stoll, 1969; Mehta and Wong, 1973; Morse et al., 1973; and Takata, 1974). It is an interactive model written in both FORTRAN and ZBASIC and runs on PDP 11/40, 11/03, 11/24, VAX 11/780, Macintosh, and IBM compatible PCs.

Model description

BURNSIM considers the skin to be represented as 12 chunks or nodes (See Figure 2). Seven additional nodes can be inserted between the first and second nodes when exposures are mild and burn damage is likely to be shallow (Figure 2). BURNSIM solves the Fourier heat conduction equation to find temperature as a function of time at each node. Then total damage at each node is found by computing the damage integral at each depth. The transition between normal and damaged skin is defined as that depth where the damage integral is equal to one. For a more detailed description of the mathematics of BURNSIM consult Appendix A. BURNSIM source code (FORTRAN version) can be found in Appendix B.

Getting started

BURNSIM has been supplied to you in either source or compiled form. The following instructions are intended to help you use the model. The instructions and comments are based, in part, on feedback received from several users who have attempted to get started without the benefit of this manual. If you have problems using BURNSIM please do not hesitate to call the author at DSN 785-3931 or (513) 255-3931. Future versions of this manual will incorporate your comments and suggestions so that we may continue to improve BURNSIM and to distribute updated versions to the users.

The first step is to load the code for the model into your computer from the medium provided. This step has many versions. Only one example is given because it is assumed that if you are using this model you are sufficiently computer literate to load and compile the source code on your system.

PC Example: BURNSIM.FOR, REN12.DAT on floppy disk.

To run off hard disk:

Set default disk drive to a:

Put diskette in a:

Type DIR (rtn)

BURNSIM.FOR REN12.DAT FLUX.DAT BURNSIM.EXE

A>CD C:

C>MD C:\BURNSIM

C>CD C:\BURNSIM

C>COPY a:*. * c:

C:\BURNSIM>DIR

BURNSIM.FOR REN12.DAT FLUX.DAT BURNSIM.EXE

C:\BURNSIM>

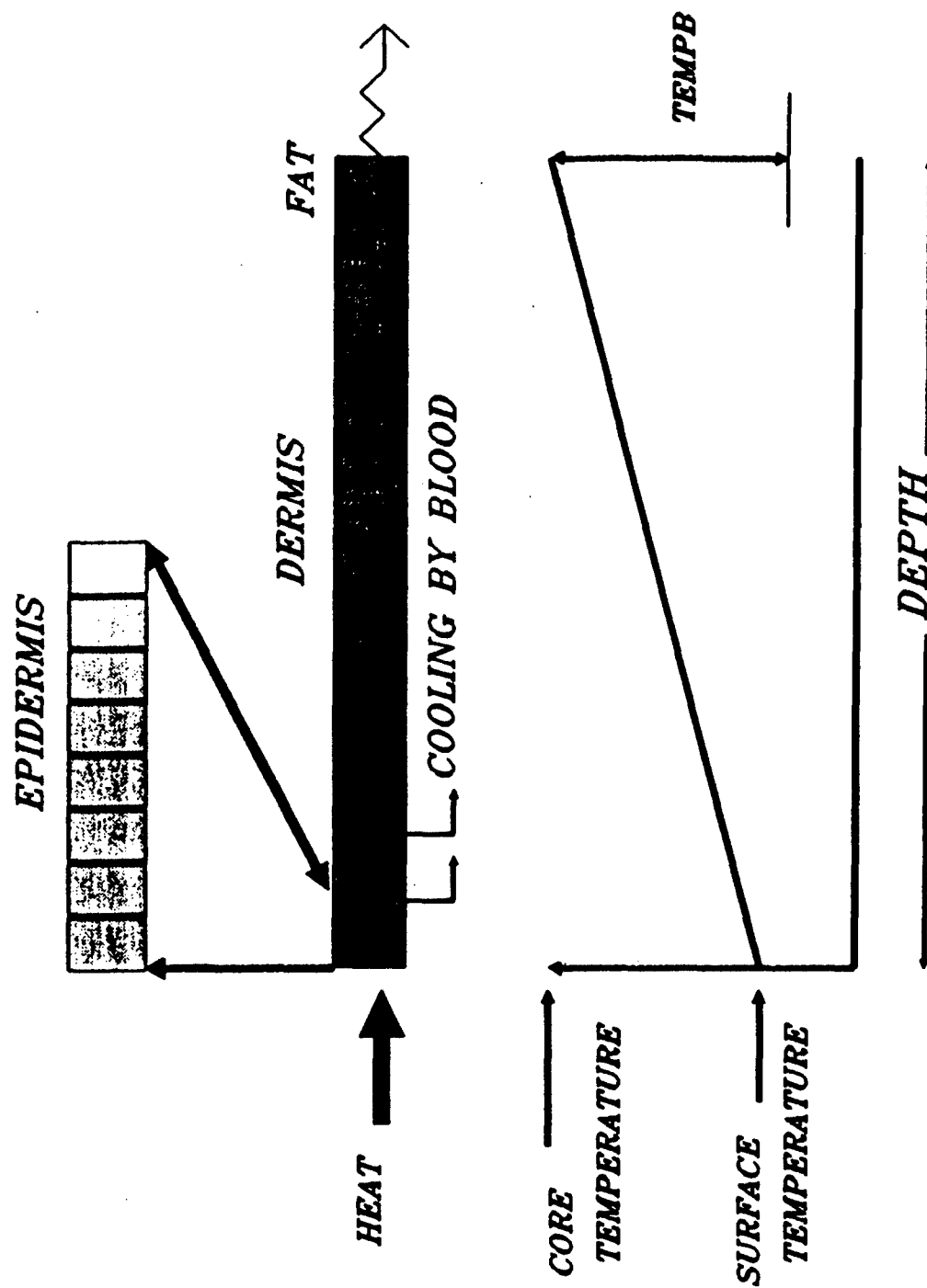


Figure 2. Skin representation

At this point you have made a directory on your hard disk for BURNSIM and copied the files from the floppy to the new directory. The file REN12.DAT contains the initial values of all the variables which are changeable within BURNSIM. Some of these values such as the conductivity and heat capacity for each node can only be changed by creating a new REN12.DAT with an editor or word processing program (see Appendix C for the layout of REN12.DAT). The model expects a flat ASCII file, so if you use a word processor, save the file as an ASCII text file and not a document. Other values such as exposure time (ETIME) can be changed interactively as described below.

To run BURNSIM invoke the command for your system, e.g. RUN BURNSIM or BURNSIM. You will next see the following on the screen:

BURNSIM <CR>

The first screen that you see is shown below:

WELCOME TO BURNSIM. TO BEGIN RUNNING THE PROGRAM, BURNSIM FIRST NEEDS TO KNOW THE NAME OF THE FILE THAT YOU WANT TO STORE THE OUTPUT DATA IN. THIS FILE WILL CONTAIN ALL OF THE INPUT PARAMETERS AS WELL AS THE OUTPUT FOR EACH ITERATION THE MODEL PERFORMS. THIS FILE CAN BE CALLED ANYTHING UP TO EIGHT CHARACTERS LONG.

PLEASE ENTER A NAME FOR THE OUTPUT FILE: OUTFILE <CR>

The next screen is shown below:

NEXT BURNSIM WILL SHOW YOU THE PRESENT INPUT PARAMETERS. UNDER THE LIST OF PARAMETERS YOU WILL SEE A QUESTION ASKING IF YOU WISH TO CONTINUE. IF YOU WANT TO EXIT THE PROGRAM AT THAT POINT, TYPE N. OTHERWISE TYPE Y.

TO CONTINUE ON TO THE LIST OF PARAMETERS TYPE A <CR>.

The following screen will appear:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMP10 = 32.5000	DENS = 1.00000	Q1 = 3.54000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 0
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WISH TO CONTINUE? TYPE Y OR N Y <CR>

Answer yes (Y) to continue and you will be presented with the following choices:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:

- 1 - CHANGE SELECTED INITIAL VALUES
- 2 - NO CHANGES---CONTINUE RUNNING THE PROGRAM
- 3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER: 1 <CR>

Choose #1 to change the set up values. This will give you the following screen:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = 3.54000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the input values using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2

15=ITIME	16=ABSORBTIVITY	
17=BOIL	18=EXTRA NODES	
19=BLOOD	20=APL1	
21=APLN1	22=APL2	
23=APLN2	24=ADE1	25=ADE2

Choose the number representing the parameter you wish to change. The definition of these parameters is in Table I. For example, set up one of Stoll's published cases (Weaver and Stoll, 1969). In this case, the human skin was exposed for 5.6 seconds at 0.4 cal/cm²-sec. The skin was blackened with India ink to set the absorbtivity at 94 percent. Start by choosing #3 to set the incident flux level, Q1. The model responds with:

ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE
IS TO BE USED): <CR>

Since Stoll's case has a constant flux value, type a <CR> and the following will appear on the screen:

CONSTANT Q-VALUE = 3.5400000 INPUT NEW VALUE: 0.4 <CR>

The old value was 3.54000 and the new value entered was 0.4 cal/cm²-sec.

If you do later simulations where you wish to read in a file of varying flux values instead of using a constant flux value, type the name of the flux file in response to the following statement:

ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE
IS TO BE USED): FLUX.DAT

The file FLUX.DAT is the example flux file given on the disk. When creating flux files to be read into BURNSIM, remember that the file name can be no more than eight characters in length including the .DAT ending. Also the file must contain only one column of data, the flux data, in units of cal/cm²-sec. The number of points in the flux file and the sample interval between points must be known, too.

Continue to input responses to the following statements concerning the flux file as they appear on the screen:

ENTER FLUX ID (UP TO 8 CHARACTERS): IDFLUX <CR>

The FLUX ID can be any combination of 8 characters.

ENTER THE NUMBER OF POINTS IN THE FLUX PROFILE: 100 <CR>

The maximum number of points that can be read in is 600.

ENTER THE SAMPLE INTERVAL IN SECONDS: 0.1 (CR)

*** Note: When using a flux file for the incident flux, the exposure time (ETIME) variable must be set equal to the number of points in the flux file minus one times the sample interval in seconds. For this example, $ETIME = (100 - 1) \times (0.1) = 9.9$ seconds.

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2
15=ITIME	16=ABSORBTIVITY
17=BOIL	18=EXTRA NODES
19=BLOOD	20=APL1
21=APLN1	22=APL2

23=APLN2

24=ADE1

25=ADE2

18 <CR>

THE NUMBER OF EXTRA NODES IS: 0 INPUT NEW VALUE: 7 <CR>

ENTER NEW VALUES SEPARATED BY A COMMAS, OR A <CR>

IF THE PROGRAM IS TO CALCULATE VALUES. 25.,50.,75.,100.,125.,150.,175.

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2
15=ITIME	16=ABSORBTIVITY
17=BOIL	18=EXTRA NODES
19=BLOOD	20=APL1
21=APLN1	22=APL2

23=APLN2

24=ADE1

25=ADE2

19 <CR>

THE VALUE FOR BLOOD IS: .00100 INPUT NEW VALUE: 0.0007 <CR>

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00070		

APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2
15=ITIME	16=ABSORBTIVITY
17=BOIL	18=EXTRA NODES
19=BLOOD	20=APL1
21=APLN1	22=APL2
23=APLN2	24=ADE1
	25=ADE2

8 <CR>

THE VALUE FOR ETIME IS: 3.02000 INPUT NEW VALUE: 5.6 <CR>

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 5.60000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00070		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME	
2=DENS	9=PL1	
3=Q1	10=PLN1	
4=BL	11=PL2	
5=AK	12=PLN2	
6=JINC	13=DE1	
7=TEMPB	14=DE2	
15=ITIME	16=ABSORBTIVITY	
17=BOIL	18=EXTRA NODES	
19=BLOOD	20=APL1	
21=APLN1	22=APL2	
23=APLN2	24=ADE1	25=ADE2

16 <CR>

THE VALUE FOR ABSORB IS: 0.61300 INPUT NEW VALUE: 0.94 <CR>

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMP10 = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .94000	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 5.60000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00070		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N N

At this point all of the input values for Stoll's example case have been set, so the answer here is no (N).

NOTE: If you inadvertently answer yes (Y) to make changes, and then decide not to make any, type a <CR> to exit the "PICK A NUMBER" menu, and the following question will appear:

DO YOU WISH TO CONTINUE? TYPE Y OR N Y <CR>

Type yes (Y) to continue on with the present run.

Now that the correct parameters are set up, select #2 to proceed:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:

- 1 - CHANGE SELECTED INITIAL VALUES
- 2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
- 3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER: 2 <CR>

You are now ready to run the program. BURNSIM will ask you for some file names in which to store the data and summaries.

ENTER THE MODEL NAME OR DESCRIPTION (UP TO 80
CHARACTERS). THIS INFORMATION WILL BE USED
AS A TITLE ON THE SUMMARY PAGE.

TEST OF A. STOLL'S .4CAL 5.6 SEC CASE FOR USER'S MANUAL <CR>

The following screen appears:

NOW ENTER THE SUMMARY FILENAME (UP TO 8
CHARACTERS). THIS FILE WILL CONTAIN A
SUMMARY OF THE SIMULATION. SUM1 <CR>

Any name up to 8 characters can be used.

The next screen then appears:

NOW ENTER THE TEMPERATURE FILE (UP TO 8 CHARACTERS).
THIS FILE WILL CONTAIN A LIST OF THE TEMPERATURES
AT THE VARIOUS NODES DURING THE SIMULATION. TFILE1 <CR>

Any name up to 8 characters can be used.

While calculating, the model prints the following on the screen:

T=	XTIME=	TIME=
32.50	0.0000E+00	0.000000
32.91	0.0000E+00	
33.32	0.0000E+00	
33.73	0.0000E+00	
34.14	0.0000E+00	
34.55	0.0000E+00	
34.95	0.0000E+00	
35.36	0.0000E+00	
35.77	0.0000E+00	
36.18	0.0000E+00	
36.59	0.0000E+00	
37.00	0.0000E+00	

BLUD =.00000

T=	XTIME=	TIME=
32.96	0.0000E+00	0.010000
32.92	0.0000E+00	
33.32	0.0000E+00	
33.73	0.0000E+00	
34.14	0.0000E+00	
34.54	0.0000E+00	
34.95	0.0000E+00	
35.36	0.0000E+00	
35.77	0.0000E+00	
36.18	0.0000E+00	
36.59	0.0000E+00	
36.99	0.0000E+00	

BLUD =.00000

T=	XTIME=	TIME=
44.40	0.0000E+00	1.000000
40.02	0.0000E+00	
37.25	0.0000E+00	
35.71	0.0000E+00	
35.03	0.0000E+00	
34.89	0.0000E+00	
35.04	0.0000E+00	
35.33	0.0000E+00	
35.67	0.0000E+00	
36.01	0.0000E+00	
36.32	0.0000E+00	
36.64	0.0000E+00	

BLUD =.00003

T=	XTIME=	TIME=
49.19	0.0000E+00	2.000000
44.62	0.0000E+00	
41.24	0.0000E+00	
38.86	0.0000E+00	
37.29	0.0000E+00	
36.36	0.0000E+00	
35.90	0.0000E+00	
35.76	0.0000E+00	
35.83	0.0000E+00	
36.02	0.0000E+00	
36.27	0.0000E+00	
36.60	0.0000E+00	

BLUD =.00007

. part of the sequence omitted to save space.

\\

T=	XTIME=	TIME=
44.50	0.0000E+00	13.000000
44.44	0.0000E+00	
44.32	0.0000E+00	
44.13	0.0000E+00	
43.81	0.0000E+00	
43.37	0.0000E+00	
42.81	0.0000E+00	
42.13	0.0000E+00	
41.36	0.0000E+00	
40.50	0.0000E+00	
39.59	0.0000E+00	
38.43	0.0000E+00	

BLUD =.00045

T=	XTIME=	TIME=
44.02	0.0000E+00	14.000000
43.97	0.0000E+00	
43.86	0.0000E+00	

43.70	0.0000E+00
43.43	0.0000E+00
43.03	0.0000E+00
42.52	0.0000E+00
41.90	0.0000E+00
41.17	0.0000E+00
40.36	0.0000E+00
39.49	0.0000E+00
38.38	0.0000E+00

BLUD =.00049

T=	XTIME=	TIME= 14.040000
44.00	0.0000E+00	
43.95	0.0000E+00	
43.85	0.0000E+00	
43.69	0.0000E+00	
43.41	0.0000E+00	
43.02	0.0000E+00	
42.51	0.0000E+00	
41.89	0.0000E+00	
41.17	0.0000E+00	
40.36	0.0000E+00	
39.48	0.0000E+00	
38.38	0.0000E+00	

BLUD =.00049

At the conclusion of the calculations, the following information appears on the screen:

W=1 LIES ABOVE NODE 2. INTERCOLLATING VALUES OF D
AND W COMPUTED FROM INTERPOLATED VALUES OF D AND
TEMPERATURE.

MAXIMUM TEMPERATURE = 60.056

THRESHOLD DEPTH = 104.6

FINAL TIME = 14.04

TIME TO PAIN = 1.59

TYPE A <CR> TO CONTINUE. <CR>

The next screen asks if you want to reformat the file so that it can be brought into the HARVARD GRAPHICS shell to make a plot.

DO YOU WANT TO PLOT THE TEMPERATURE VS. TIME
IN HARVARD GRAPHICS? Y OR N Y <CR>

If you answer yes (Y) then you must type in a new file name for the HARVARD GRAPHICS temperature file.

THE TEMPERATURE DATA IS STORED IN FILE: TFILE1

ENTER THE FILE TO STORE THE HARVARD GRAPHICS
TEMPERATURES USING UP TO 12 CHARACTERS
INCLUDING THE ENDING .DAT HGTFILE1.DAT

The following will then appear on the next screen:

THE MODEL OUTPUT IS IN FILE: OUTFILE
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

THE TEMPERATURES AT EACH NODE ARE IN FILE: TFILE1
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

THE TEMPERATURES FOR THE HARVARD GRAPHICS PLOTS ARE IN FILE:
HGTFILE1.DAT USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM
TO SEE IT.

THE SUMMARY PRINTOUT IS IN FILE: SUM1
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

TYPE A <CR> TO CONTINUE. <CR>

The following question will appear next on the screen:

DO YOU WANT TO CONTINUE? Y OR N

At this point choosing yes (Y) takes you back to the following screen:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:

- 1 - CHANGE SELECTED INITIAL VALUES
- 2 - NO CHANGES---CONTINUE RUNNING THE PROGRAM
- 3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER:

If you choose no (N) at the "DO YOU WANT TO CONTINUE?" you will see the
following question:

DO YOU WANT TO DO ANOTHER RUN? Y OR N

If you answer yes (Y) you will be taken back to the following screen
to change any desired input parameters:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMP10 = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .94000	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 5.60000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00070		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N

If you answer no (N) to "DO YOU WANT TO DO ANOTHER RUN?", you will exit the BURNSIM program.

If you type the file SUM1 the following appears on the screen:

MODEL NAME OR DESCRIPTION: TEST OF A. STOLL .4CAL 5.6SEC CASE

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMP10 = 32.50000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .94000	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 5.60000	ITIME = 80.00000	NXTRA = 7
BLOOD =		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

FLUX FILE I.D.: .00 2

FLUX(I)=
1 .400 2 .400

W= .21973E+01
W= .12061E+00
W= .14088E-01
D= -.16000E+02

D= .52983E+01
D= .59915E+01

W=1 LIES ABOVE NODE 2. INTERCOLLATING VALUES OF D
AND W COMPUTED FROM INTERPOLATED VALUES OF D AND
TEMPERATURE.

W= .10360E+01
W= .86923E+00
W= .73320E+00

D= .46052E+01
D= .48283E+01
D= .50106E+01

W =	.21973E+01	AT DEPTH (IN MICRONS)=	.112535E-06
W =	.18217E+01	AT DEPTH (IN MICRONS)=	25.0000
W =	.14992E+01	AT DEPTH (IN MICRONS)=	50.0000
W =	.12423E+01	AT DEPTH (IN MICRONS)=	75.0000
W =	.10360E+01	AT DEPTH (IN MICRONS)=	100.000
W =	.86923E+00	AT DEPTH (IN MICRONS)=	125.000
W =	.73320E+00	AT DEPTH (IN MICRONS)=	150.000
W =	.62140E+00	AT DEPTH (IN MICRONS)=	175.000
W =	.12061E+00	AT DEPTH (IN MICRONS)=	200.000
W =	.14088E-01	AT DEPTH (IN MICRONS)=	400.000
W =	.47704E-02	AT DEPTH (IN MICRONS)=	600.000
W =	.21844E-02	AT DEPTH (IN MICRONS)=	800.000

MAXIMUM TEMPERATURE = 60.056

THRESHOLD DEPTH = 104.6

FINAL TIME = 14.04

TIME TO PAIN IS 1.59 SECONDS.

If you plot the data saved in TFILE1 and overlay Stoll's measured data, we get the following:

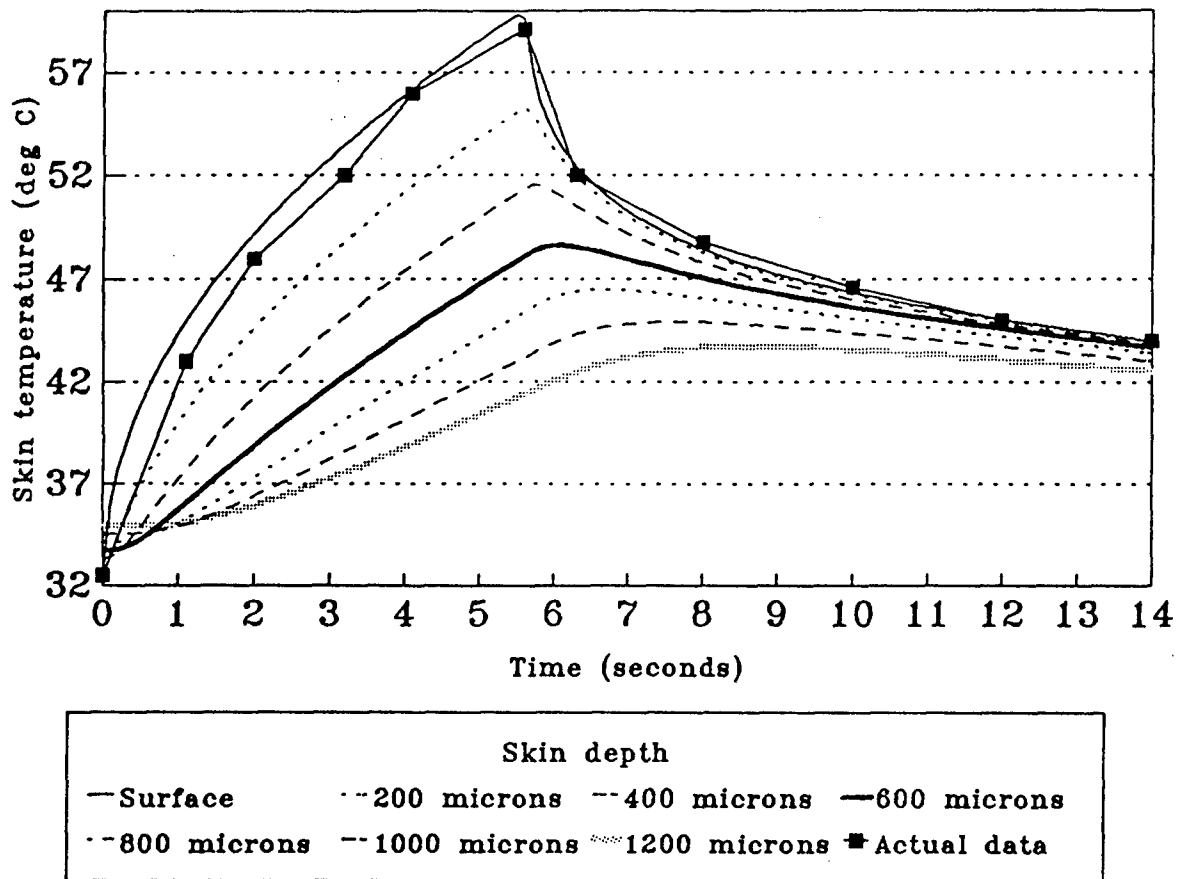


Figure 3. Skin temperatures at first six nodes calculated with Burnsim for Stoll's Data

Notice that there is reasonable fit between the computed temperature profiles and the recorded temperature. The predicted depth is 104.9 microns. Stoll observed a threshold blister, hence the damage should be between 80 μ m and 120 μ m.

Helpful hints

This section is devoted to explaining the inputs to the model and some hints about how to set up the model for special cases. The inputs are summarized in Table A-1.

There are nine special cases which have been found by previous users. First, for short exposures of less than 1 second, change the calculation interval (AK) from its normal value of .01 second to some value which is at least 100 times less than the duration. Thus, for an

exposure of 0.1 sec use $AK = 0.001$ second. Second, if the skin has been blackened, e.g., with india ink, use an absorptivity of about 0.92 to 0.94. Third, the default value of 0.613 for absorptivity assumes that 100 percent of the convective energy is absorbed, only 60 percent of the radiative energy is absorbed, and 5 percent of incident radiation is intercepted by hair. Thus, assuming

- 1) $Q \text{ incident} = 0.1 q_i \text{ (convective)} + 0.9 q_i \text{ (radiative)}$
- 2) 5 percent radiative is not absorbed because of hair stubble,

$$\text{then } Q = 0.1 q_i + 0.6(.9)(.95)q_i = 0.613 q_i$$

Fourth, use NXTRA 7 especially for mild exposures so that shallow burn depths are calculated more accurately. Fifth, a value of 0.0007 for Blood works best for shallow human burns.

Sixth, new values for DE1, DE2, PL1, PLN1, PL2, and PLN2 can be calculated if you wish to try rate constants published by other authors (see model derivation in Appendix A).

Seventh, it is possible to calculate new thermal properties based on humidity changes. Read the paper on thermal properties published in the journal Burns (Knox et al. 1986).

Eighth, the model currently assumes that ambient temperature is 23.9°C. Thus, during cool down the surface loses heat to a 23.9°C environment. This number can be changed only in the source code in the following line:

```
If (TIME.GE.ETIME)Q1 = -5.E-4*(t(1)-23.9)
```

Nine, for very severe exposures, where water boils in more than the first node, the thermal property recalculations routine causes an instability in the cool down phase. This can be seen if the data are plotted and can be avoided by setting the boil temperature to a much higher value. A permanent fix for this bug will appear in the next version of BURNSIM.

References

- Crank, J., and Nicholson, P. 1947. Proceedings Cambridge philosophical society. 43:50
- Henriques, F. C. 1947. Studies of thermal injury. V. The predictability and the significance of thermally induced rate processes leading to irreversible epidermal injury. Archives of pathology. 43:489-502.
- Knapp, S. C., and Knox, Francis, S. III. 1982. Human response to fire and personnel protection measures. AGARD/NATO Pep lecture series no. 123 on "Aircraft Fire Safety", 7-16 June, at Oslo, Norway, London, England and Washington, D.C.
- Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978a. How to measure the burn-preventive capability of nonflammable textiles: A comparison of the USAARL porcine bioassay technique with mathematical models. Burns. 5(1):19-29. Also reprinted as USAARL Report No. 79-5. 1979. (Uses model and sensor output to predict burns.)
- Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978b. Biomedical constraints on thermal protective flight clothing design: A bio-engineering analysis. In Operational helicopter aviation medicine: AGARD/NATO Panel Specialists' Meeting, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. pp. 63-1--63-11. AGARD-CP-255.
- Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978c. Mathematical models of skin burns induced by simulated postcrash fires as aids in thermal protective clothing design and selection. In Proceedings of the army science conference, June 20-22; West Point, NY, 267-281. Vol II (AD-A056437). Also published as USAARL Report No. 78-15.
- Knox, F. S., III, Knapp, S. C., McCahan, G. R., Jr., and Wachtel, T. L. 1979. Bioassay of thermal protection afforded by candidate flight suit fabrics. Journal of aviation, space, and environmental medicine. 50(10):1023-1030.
- Knox, F. S., III. 1979. Predictability of burn depth: Data analysis and mathematical modeling based on USAARL's experimental porcine burn data. Shreveport, LA: Louisiana State University School of Medicine, Department of Physiology and Biophysics. Contract DAMD17-77-7004.
- Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1980. Burn prediction model for thermally protective clothing evaluation. Paper presented at the annual meeting of the Aerospace Medical Association, 12-15 May.

- Knox, F. S., III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1986. Thermal properties calculated from measured water content as a function of depth in porcine skin. Burns. 12(8):556-562.
- Mehta, A., and Wong, F. 1973. Measurement of flammability and burn potential of fabrics. (Summary report December 1971-January 1973.) Cambridge, MA: Fuels Research Laboratory, Massachusetts Institute of Technology Project DSR 73884.
- Moritz, A. R. 1947. Studies of thermal injury. III. The pathology and pathogenesis of cutaneous burns, an experimental study. American journal of pathology. 23:915-941.
- Morse, H. L., Thompson, J. G., Clark, K. J., Green, K. A., and Moyer, C. B. 1973. Analysis of the thermal responses of protective fabrics. Wright-Patterson Air Force Base, OH: Air Force Materials Laboratory, Air Force Systems Command. Technical Report AFML-TR-73-17.
- Reneau, D. D., and O'Young, Nelson. 1976, 1977, 1978. Consultation report to F. S. Knox. Shreveport, LA: Louisiana State University Medical Center, Department of Physiology and Biophysics. U.S. Army Contract Nos. DABT01-75-C-0257 and DAMD-17-77-C-7004.
- Rushmer, R. F., Buettner, K. J. K., Short, J. M., and Odland, G. F. 1966. The skin. Science. 154(3747):343-348.
- Stoll, A., and Greene, L. C. 1959. Relationship between pain and tissue damage due to thermal radiation. Journal of applied physiology. 14:373.
- Stoll, A. M., and Chianta, M. A. 1971. Heat transfer through fabrics as related to thermal injury. Transactions-New York academy of science. Vol 33(7):649-670. November.
- Takata, A. 1974. Development of criterion for skin burns. Aerospace medicine. 45(6):634-637.
- Weaver, J. A., and Stoll, A. M. 1969. Mathematical model of skin exposed to thermal radiation. Aerospace medicine. 40:24-30.

Bibliography

- Albright, J. D., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971a. The testing of thermal protective clothing in a reproducible fuel fire environment, phase I report: a feasibility study. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR 71-3-3-2.
- Albright, J. D., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971b. The testing of thermal protective clothing in a reproducible fuel fire environment, a feasibility study. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-24. (Defines postcrash fire environment and assesses the proper directions of future research.)
- Anderson, W. A. D. 1966. Pathology. 5th ed., Vol. 1. St. Louis, MO: The C.V. Mosby Company.
- Archanbeau, J. O., Fairchild, R. G., and Commerford, S. L. 1966. Response of skin of swine to increasing exposure of 250-KVP X-ray. In: Bustad, L.K. and McClellan, R.O., ed. Swine in biomedical research. Seattle: Frayn. 463.
- Armed Forces Institute of Pathology. AFIP manual of histologic and special staining technique. 2d ed. New York: Blackstone Division of McGraw Hill Book Company.
- Artz, C. P., and Moncrief, J. A. 1969. The treatment of burns. 2d ed. Philadelphia, PA: W.B. Saunders Company.
- Bader, B. E. 1965. Heat transfer in liquid hydrocarbon fuel fires. In: Chemical Engineering Progress Symposium Series. pp. 78-90. Vol. 61, No. 56. Sandia Albuquerque, NM.
- Basar, Erol. 1976. The circulatory autoregulation. In: Biophysical and physiological systems analysis. Reading, MA: Addison-Wesley Publishing Company. Chapter 4.
- Belason, P. H., Castle, G., Crowley, D., and D'Auanzo, L. 1970. A fire simulation facility for materials response testing. Fire technology. 15(3).
- Berkley, K. M. 1954. Evaluation of surface appearance of burns by depth of damage. Rochester, NY: University of Rochester. Atomic Energy Report UR-337.
- Berkley, K. M., Pearse, H. E., and Davis, T. P. 1954. Studies of flash burns: the influence of skin temperature in the production of cutaneous burns in swine. Rochester, NY: University of Rochester. Atomic Energy Project UR-338.
- Berkley, K. M. 1957. The effect of air space on sub-fabric burns in swine. Rochester, NY: The University of Rochester. Atomic Energy Project UR-490.
- Billote, J. B., Coumans, R. J. K., Guthy, E. A., Constable, J. D., and Burke, J. F. 1969. Effect of topical sulfamylon on wound healing. Surgical forum. 20:71.
- Blinov, V. I., and Khuiakov, G. N. 1957. Certain laws governing the diffusive burning of liquids. Academic Nauk, SSSR Doklady. 113:1094-1098. (Reviewed by H.C. Hottel, 1959, Fire research abstracts and reviews 1, pp 41-44.)

- Bruce, G. H., Peaceman, D. W., Rackford, H. H., and Rice, J. D. 1953. Transactions American institute of mining, metallurgical and petroleum engineers. 198:79.
- Buettner, K. 1952. Effects of extreme heat and cold on human skin. III. Numerical analysis and pilot experiments on penetrating flash radiation effects. Journal of applied physiology. 5(5):207-220.
- Burgess, D. S., Grumer, J., and Wolfhard, H. G. 1961. Burning rates of liquid fuels in large and small open trays. In: Berl, W. G., ed. The use of models in fire research. Publication. 786. Washington, DC: National Academy of Sciences - National Research Council. 68-75.
- Bustad, L. K; 1966, Pigs in the laboratory. Scientific American. 214:94.
- Bustad, L. K., and McClellan, R. O., ed. 1966. Swine in biomedical research. Seattle, WA: Frayn.
- Butterfield, W. S. H., and Dixey, J. R. B. 1951. Burns from atomic bombs, Journal royal naval medical science. 37:9.
- Callen, H. B. 1960. Thermodynamics. New York, NY: John Wiley & Sons, Inc.
- Carhart, W. H., and Affens, W. A. 1969. Flammability of aircraft fuels. Fire technology. 5(1):16.
- Carslaw, H. S., and Jaeger, J. C. 1959. Conduction of heat in solids. Oxford, Oxford Press University. QC 321.C28
- Conley, D. W. 1965. Post-crash fire-fighting studies on transport category aircraft. Atlantic City, NJ: Federal Aviation Agency. Report RD-65-50.
- Cooper, T. E., and Trezek, G. J. 1971. Correlation of thermal properties of some human tissue with water content. Journal of aerospace medicine. 42(1):24-27.
- Crank, J., and Nicholson, P. 1947. Proceedings Cambridge philoslogical society. 43:50.
- Dalzell, W. H., and Sarofim, A. F. 1969. Optical constants of soot and their application to heat-flux calculations. Journal of heat transfer transactions of the American society of mechanical engineers. 100-104.
- Derksen, W. L., Delhevy, G. P., and Monahan, T. I. 1960. Thermal and optical properties of the NML skin stimulant. New York, NY: Naval Materials Laboratory, New York Naval Shipyard. Laboratory Project 5046-3.
- Diller, K. R. 1985. Analysis of skin burns. In Shitzer A., Eberhart, R. C. eds: Heat transfer in medicine and biology: Analysis and applications, Vol 2. New York: Plenum Publishing Co. 85-134.
- Dumphy, J. E. 1966. Whither repair? In: Levenson, S. M., Stein, J. M., and Grossblatt, N. eds, Wound healing: Proceedings of workshop. Washington, DC: National Academy of Sciences, National Research Council. p. 4.
- Emmons, H. W. 1961. Some observations on pool burning. In: Berl, W. G., ed, The use of models in fire research. Washington, DC: National Academy of Sciences - National Research Council. Publication 786. 50-67.

- Emmons, H. W. 1964. Fundamental problems of the free burning fire. Tenth symposium (international) on combustion. pp. 951-964. Combustion Institute, Pittsburgh, PA.
- Evans, E. I., Brooks, J. W., Schmidt, F. H., Williams, R. C., and Ham, W. T. 1955. Flash burn studies on human volunteers. Surgery. 37:280.
- Feller, I., Flora, J. D., and Bawol, R. 1976. Baseline results of therapy for burned patients. Journal of the American medical association. 236:(17):1943-1947.
- Feller, I., Richards, K., and Crane, K. 1972. The role of flammable fabrics in severe burn injuries. In: Proceedings of the sixth annual meeting of the information council on fabric flammability. Hotel Commodore, 7 December, New York, NY.
- Fisher, J. C., Wells, J. A., and Fulwider, B. T. 1977. Do we need a burn severity grading system? Journal of trauma. 17:252.
- Forbes, P. D. 1969. Vascular supply of the skin and hair in swine. In: Montag, W., and Dobson, R. L., eds. Hair growth, advances in biology of skin. Oxford, MA: Pergamon. 9, 479.
- Fowler, J. F. 1963. Experiments with fractionated X-ray treatment of the skin of pigs. British journal of radiology. 36:188-196.
- Gaydon, A. G., and Wolfhard, H. G. 1960. Flames, their structure, radiation and temperature. London: Chapman and Hall Ltd.
- Gillman, T., and Ordman, L., 1966. Histogenesis of healing incised and excised wounds in young pigs. In: Bustad, L.K., and McClellan, R.O., eds. Swine in biomedical research. Seattle, WA: Frayn. p. 299.
- Gordon, W., and McMillen, R. D. 1965. Temperature distribution within aircraft-fuel fires. Fire technology. 1(1):52.
- Grillo, H. D. 1966. Open wounds as an experimental system. In: Levenson, S. M., Stein, J. M., and Grossblatt, N., eds. Wound healing: Proceedings of a workshop. Washington, DC: National Academy of Sciences - National Research Council. pp. 261-269.
- Griswold, J. 1946. Fuels, combustion, and furnaces. New York, NY: McGraw-Hill.
- Hardy, J. D. 1962. Physiological effects of high intensity infrared heating. American society heating and refrigeration engineers journal.
- Hardy, J. D., and Soderstrom, G. F. 1938. Heat loss from the nude body and peripheral blood flow at temperature of 22° to 35°C. Journal of nutrition. 16:493.
- Henriques, F. C. 1947. Studies of thermal injury. V. The predictability and the significance of thermally induced rate processes leading to irreversible epidermal injury. Archives of pathology. 43:489-502.
- Henriques, F. C., and Moritz, A. R. 1947. Studies of thermal injury. I. The condition of heat to and through skin and the temperatures attained therein. A theoretical and an experimental investigation. American journal of pathology. 23:531-549.
- Hinshaw, J. R. 1963. Progressive changes in the depth of burns. Archives of surgery. 87:993-997.

- Hinshaw, J. R., and Payne, F. W. 1963. The restoration and remodeling of the skin after a second degree burn. Surgery, gynecology and obstetrics. 117:738-744.
- Hirschfelder, J. O. 1962. Some remarks on the theory of flame propagation. Ninth symposium (international) on combustion. Combustion Insitute, Pittsburgh, PA. pp. 553-559.
- Jobb, K. Y. F., and Kennedy, P. C. 1970. Pathology of domestic animals. 2d ed., Vol. 2. New York, NY: Academic Press.
- Karasek, J., and Oehlert, W. 1968a. Die ultrastruktur der epidermis des schweines. I. Stratum basale und stratum spinosum. Zeitschrift fuer mikroskopische anatoische forschung. 78:133.
- 1968b. Die ultrastruktur der epidermis des schweines. II. Stratum granulsoum and corneum. Zeitschrift fuer mikroskopische anatoische forschung. 79:157.
- Knapp, S. C., Allemond, P. A., and Karney, D. H. 1978. Helicopter crashworthy fuel systems and their effectiveness in preventing thermal injury. In: Operational helicopter aviation medicine: AGARD/NATO Panel Specialists' Meeting, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. pp. 61-1-61-7. AGARD-CP-255.
- Knapp, S. C., and Knox, F. S., III. 1982. Human response to fire and personnel protection measures. AGARD/NATO PEP lecture series no. 123 on "Aircraft fire safety." 7-16 June, at Oslo, Norway, London, England, and Washington, D.C.
- Knox, F. S., III, McCahan, G. R., Jr., Wachtel, T. L., Trevethan, W. P., Martin, A. S., DuBois, D. R., and Keiser, G. S. 1971. Engineering test of lightweight underwear of the winter flight clothing system: Thermal protection. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-19.
- Knox, F. S., III. 1971. Protective clothing for aviators. Presented at the Third U.S. Army Aviation Accident Prevention Conference; August 18-19; Fort Rucker, AL.
- 1972a. Preliminary results, conclusions and recommendations from the evaluation of helmet flammability - DH-132 and T56-6 helmets. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-72-17-3-5.
- 1972b. Realistic evaluation of fabrics for thermal protective clothing. Presented to the Survival and Flight Equipment Association 10th Annual Symposium; October 2-5; Phoenix, AZ.
- Knox, F. S., III, McCahan, G. R., Jr., and Wachtel, T. L. 1972. The use of the pig as a bioassay substrate for evaluation of thermal protective clothing and physical sensor calibration. Presented at the Eighth Scientific Session of the Joint Committee on Aviation Pathology; October 8-12; Colorado Springs, CO. Also presented at the American Burn Association 5th Annual Meeting; 1973 April 6; Dallas, TX (16mm color, sound film, 20 min.). Published in Journal of aerospace medicine. 45:933, 1974.
- Knox, F. S., and Bailey, R. W. 1973. Results, conclusions and recommendations from the evaluation of helmet flammability - DH-132 and T56-6 helmets. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-73-9-3-4.

- Knox, T. (F. S., III), and Knapp, S. C. 1975. Testing for thermal protection. Presented at the 4th National Flame-Free Design Conference; March 11-13; San Diego, CA.
- Knox, F. S., III, and Nockton, R. A. 1976. Data analysis and mathematical modeling based on U.S. Army Aeromedical Research Laboratory's experimental porcine burn - Phase I data. 1 July 1975 - 30 September 1976. Shreveport, LA: LSU School of Medicine, Department of Physiology and Biophysics. Contract No. DABT01-75-C-0257.
- Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978a. How to measure the burn-preventive capability of nonflammable textiles: A comparison of the USAARL porcine bioassay technique with mathematical models. Burns. 5(1):19-29. Also reprinted as USAARL Report No. 79-5. (Uses model and sensor output to predict burns.)
- 1978b. Biomedical constraints on thermal protective flight clothing design: A bio-engineering analysis. In: Operational helicopter aviation medicine: AGARD/NATO Panel Specialists' Meeting, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. pp. 63-1-63-11. AGARD-CP-255.
- 1978c. Mathematical models of skin burns induced by simulated postcrash fires as aids in thermal protective clothing design and selection. In: Proceedings of the army science conference; June 20-22; West Point, NY. pp. 267-281. Vol. II (AD-A056437). Also published as USAARL Report No. 78-15.
- Knox, F. S., III, Wachtel, T. L., and McCahan, G. R., Jr. 1978. Evaluation of four thermally protective fabrics using the USAARL bioassay method. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-9.
- Knox, F. S., III, Wachtel, T. L., Trevethan, W. P., McCahan, G. R., Jr., and Brown, R. J. 1978. A porcine bioassay method for analysis of thermally protective fabrics: A histological and burn depth grading system. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-11.
- Knox, F. S., III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1978. A porcine bioassay study of the physiological effects of fiber and dye degradation products (FDP) on burn wound healing. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-10. Also published as The effect of fiber and dye degradation products (FDP) on burn wound healing. Journal of aviation, space, and environmental medicine. October, pp. 1007-1015.
- Knox, F. S., III, Knapp, S. C., McCahan, G. R., Jr., and Wachtel, T. L. 1979. Bioassay determination of thermal protection afforded by candidate flight suit fabrics. Journal of aviation, space and environmental medicine. 50(10):1023-1030.
- Knox, F. S., III. 1979a. VIPER exhaust burn hazard. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-79-9-1-1. (Application of the model BRNSIM to assess the hazard associated with exposure to hot gases.)
- Knox, F. S., III. 1979b. Predictability of burn depth: Data analysis and mathematical modeling based on USAARL's experimental porcine burn data. Shreveport, LA: Louisiana State University School of Medicine, Department of Physiology and Biophysics. Contract DAMD17-77-7004.

- Knox, F. S. III, Sauermilch, P. W., Wachtel, T. L., McCahan, G. R., Jr., Trevethan, W. P., Lum, C. B., Brown, R. J., and Alford, L. A. 1979. A fire simulator/shutter system for testing protective fabrics and calibrating thermal sensors. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 79-4.
- Knox, F. S., III, Wachtel, T. L., and Knapp, S.C. 1980. Burn prediction model for thermally protective clothing evaluation. Presented to the Aerospace Medical Association; 12-15 May; Anaheim, CA.
- Knox, F. S., III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1986. Thermal properties calculated from measured water content as a function of depth in porcine skin. Burns. 12(8):556-562.
- Kreith, F. 1965. Principles of heat transfer. 2d ed. Scranton, PA: International Textbook Company. Chapter 4.
- Lewis, B., and von Elbe, E. 1947. Temperature: Its measurement and control in science and industry. American Institute of Physics. New York, NY: Reinhold Publishing Corp.
- Lewis, B., Pease, R. N., and Taylor, H. S. 1956. Combustion processes. Vol. II, High speed aerodynamics and jet propulsion. Princeton University Press.
- Lipkin, M., and Hardy, J. D. 1954. Measurement of some thermal properties of human tissues. Journal of applied physiology. 7(2):212-217.
- Lum, C. B. 1972. Trip report: Microscopic burn damage data - consultation with Dr. Walter Trevethan. Pensacola, FL: Naval Aerospace Medical Institute; November 27-28.
- Lum, C. B. 1973. Instrumented helicopter burn. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-73-6-3-2.
- Lyon, J. L., Davis, T. P., and Pearse, H. E. 1955. Studies of flash burns: The relation of thermal energy applied and exposure time to burn severity. Rochester, NY: University of Rochester. Atomic Energy Report 394.
- Lyon, J. L., Emery, A. J., Jr., Pearse, H. E., and Davis, T. P. 1955. Rochester, NY: University of Rochester. Atomic Energy Project Report UR-401.
- Madden, J. E., Edlich, R. F., Prusak, M., and Wangenstein, O. H. 1971. The molecular basis for the antiseptic activity of rosaniline dyes in the contaminated wound. Surgical forum. 22:63.
- Maggio, R. C. 1956. A molded skin stimulant material with thermal and optical constants approximating those of human skin. New York, NY: Naval Materials Laboratory, New York Naval Shipyard. Laboratory Project 5046-3. Part 105.
- Magnus, G. 1961. Tests on combustion velocity of liquid fuels and temperature distribution in flames and beneath surface of the burning liquid. In: Berl, W. G., ed. The use of models in fire research. Publication 786. Washington, DC: National Academy of Sciences - National Research Council.
- Marcarian, H. Q., and Calhoun, M. L. 1966. Microscopic anatomy of the integument of adult swine. American journal of veterinary research. 27:765.

- McCahan, G. R., Jr., and Wachtel, T. L. 1972. Anesthesia or immobilization of domestic and miniature swine--methods and some problems. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 73-6.
- McClellan, P. O. 1968. Application of swine in biomedical research. Laboratory animal care. 18:120.
- McCoy, J. A., Micks, D. W., and Lynch, J. B. 1968. Discriminant function probability model for predicting survival in burned patients. Journal of the American medical association. 203:644-646.
- Mehta, A., and Wong, F. 1973. Measurement of flammability and burn potential of fabrics. (Summary Report December 1971 - January 1973.) Cambridge, MA: Fuels Research Laboratory, Massachusetts Institute of Technology Project DSR 73884.
- Meyer, W., and Neurand, K. 1976. The distribution of enzymes in the skin of the domestic pig. Laboratory animals. 10:347.
- Mixter, G., and Pearse, H. E. 1953. Studies of flash burns: The protection afforded by 2, 4 and 6 layer fabric combinations. Rochester, NY: The University of Rochester. Atomic Energy Project UR-261.
- Moncrief, J. A. 1969. Burns. In Schwartz, S. I., ed. Principles of surgery. New York, NY: McGraw-Hill, Inc. pp. 205-206.
- Montagna, M., and Yun, J. S. 1964. Skin of the domestic pig. Journal of investigative dermatology. 43:11.
- Montagna, W., and Yun, J. S. 1964. The skin of the domestic pig. Journal international college of surgeons. 42:11-21.
- Moritz, A. R. 1947. Studies of thermal injury. III. The pathology and pathogenesis of cutaneous burns, an experimental study. American journal of pathology. 23:915-941.
- Moritz, A. R., and Henriques, F. C. 1947. Studies of thermal injury. II. The relative importance of time and surface temperature in the causation of cutaneous burns. American journal of pathology. 23:695-720.
- Moritz, A. R., Henriques, F. C., Dutra, F. R., and Weisiger, J. R. 1947. Studies of thermal injury, IV, and exploration of the casualty - producing attributes of conflagrations, local and systemic effects of general cutaneous exposure to excessive circumambient (air) and circumradiant heat of varying duration and intensity. Archives of pathology. 43:466-488.
- Morse, H., Tichner, G., and Brown, R. 1975. Burn damage and burn depth criteria. Acurea Corp, Mountain View, CA. Aerotherm TN-75-26.
- Morse, H. L., Thompson, J. G., Clark, K. J., Green, K. A., and Moyer, C. B. 1973. Analysis of the thermal responses of protective fabrics. Wright-Patterson Air Force Base, OH: Air Force Materials Laboratory, Air Force Systems Command. Technical Report AFML-TR-73-17.
- Morton, B. R. 1964. Modeling fire plumes. Tenth symposium (international) on combustion. Combustion Institute, Pittsburgh, PA. pp. 973-982.
- Morton, J. H., Kingsley, H. D., and Pearse, H. E. 1952. Studies on flash burns: threshold burns. Surgery, gynecology, and obstetrics. 94:317.

- Moseroova, J., Behounkova, E., and Prouza, Z. 1975. Subcutaneous temperature measurements in a thermal injury. Burns. 1:267.
- Neill, D. T., Welker, J. R., and Shepceovich, C. M. 1970. Direct contact heat transfer from buoyant diffusion flames. Journal of fire and flammability. 1:289-300.
- Nielsen, H. J., and Tao, L. N. 1964. The fire plume above a large free-burning fire. Tenth symposium (international) on combustion. Combustion Institute, Pittsburgh, PA. pp. 965-972.
- Pavshkin, Y. M. 1962. The chemical composition and properties of fuels for jet propulsion. New York, NY: Pergamon Press.
- Peacock, E. E., Jr., and Van Winkle, W., Jr. 1970. Surgery and biology of wound repair. Philadelphia, PA: W.B. Saunders Co.
- Perkins, J. B., Pearse, H. E., and Kingsley, H. D. 1951. Studies on flash burns: The relation of the time and intensity of applied thermal energy to the severity of burns. Rochester, NY: University of Rochester. Atomic Energy Project Report UR-217.
- Pesman, G. J. September 1953. Appraisal of hazards to human survival in airplane crash fires. National Advisory Committee for Aeronautics Technical Note 2996, Washington DC.
- Pinkel, I. I., Preston, G. M., and Pesman, G. J. August 1952. Mechanism of start and development of aircraft crash fires. National Advisory Committee for Aeronautics Research Memorandum E52F06, Washington DC.
- Ragan, H. A., and Gillis, M. F. 1975. Restraint, venipuncture, endotracheal intubation and anesthesia of miniature swine. Laboratory animal sciences. 25:409-419.
- Ragozin, N. A. 1961. Jet propulsion fuels. New York, NY: Pergamon Press.
- Reneau, D. D., and O'Young, N. 1976, 1977, 1978. Consultation report to F. S. Knox. Shreveport, LA: Louisiana State University Medical Center, Department of Physiology and Biophysics. U.S. Army Contract Nos. DABT01-75-C-0257 and DAMD-17-77-C-7004.
- Robb, H. J. 1967. Dynamics of the microcirculation during a burn. Archives of surgery. 94:776.
- Rushmer, R. F., Buettner, K. J. K., Short, J. M., and Odland, G. F. 1966. The skin. Science. 154(3747):343-348.
- Scapicchio, A. P., Constable, J. D., and Opitz, B. F. 1967. Comparative effects of silver nitrate and sulfamylon acetate on epidermal regeneration. Surgical forum. 18:510.
- Spalding, D. B. 1962. The art of partial modeling. Presented at the Colloquium on Modeling Principles, Ninth Symposium (international) on Combustion. Combustion Institute, Pittsburgh, PA. pp. 833-842.
- Stanton, R. M., Schulman, S., and Ross, J. H. 1973. Evaluation of PBI and Nomex II for Air Force flight suits. Air Force Material Laboratory, Wright-Patterson AFB, Ohio. Technical Report AFML-TR-73-28.
- Stoll, A. M., and Hardy, J. D. 1950. Study of thermocouples as skin thermometers. Journal of applied physiology. II:532-543.

- Stoll, A., and Greene, L. C. 1959. Relationship between pain and tissue damage due to thermal radiation. Journal of applied physiology. 14:373.
- Stoll, A. M. 1962. Thermal protection capacity of aviator's textiles. Aerospace medicine. 846-850.
- Stoll, A. M., and Chianta, M. A. 1969. Method and rating system for evaluation of thermal protection. Aerospace medicine. 40(11):1232-1237.
- Stoll, A. M., and Chianta, M. A. 1970. Heat transfer through fabrics, Warminster, PA: Naval Air Development Center, Aerospace Medical Department. NADC-MR-7017.
- Stoll, A. M., and Chianta, M. A. 1971. Heat transfer through fabrics as related to thermal injury. Transactions-New York Academy of Sciences. Vol 33(7) Nov. 649-670.
- Stoll, A. 1978. Comments made during thermal protective clothing ad hoc working conference (tri-service). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory; April 3-4.
- Takata, A. N. 1957. Unpublished data prepared by Armour Research Foundation for Air Force Special Weapons Program (AFSWP-1060), Illinois Institute of Technical Research Institution, Chicago, IL.
- Takata, A. N., Rouse, J., and Stanley, T. 1973. Thermal analysis program. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. Report No. IITRI-J6286. Contract No. DA13C01-G-0309.
- Takata, A. 1974. Development of criterion for skin burns. Aerospace medicine. 45(6):634-637.
- Thring, M. W. 1952. The science of flames and furnaces. New York, NY: John Wiley and Sons, Inc.
- Torres, M., and Buchan, M. 1972. Crashworthy fuel system mishap data. Aviation digest. pp. 44-45.
- Van Wylen, J. G., and Sonntag, R. E. 1960. Fundamentals of thermodynamics. New York, NY: John Wiley & Sons, Inc.
- Vincenti, W. G., and Kruger, C. H., Jr. 1965. Introduction to physical gas dynamics. New York, NY: John Wiley & Sons, Inc. Chapter XI.
- Wachtel, T. L., and McCahan, G. R., Jr. 1973. A comparison of methods of preparing porcine skin for bioassay of thermal injury. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 73-9.
- Wachtel, T. L., McCahan, G. R., Jr., and Monafu, W. W., Jr. 1977. Fluid resuscitation in a porcine burn shock model. Journal of surgical research. 23:405-414.
- Wachtel, T. L., Knox, F. S., III, and McCahan, G. R., Jr. 1977. Methods of preparing porcine skin for bioassay of thermal injury. Military medicine. 141:536-538.
- Wachtel, T. L., Knox, F. S. III, and McCahan, G. R., Jr. 1978. A porcine bioassay method for analysis of thermally protective fabrics: A clinical grading system. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-8.

- Waldron, E. T., Smith, W. F., and Mahen, M. E. 1967. Effectiveness of aviators' garments in protecting against gasoline fires. Natick, MA: U.S. Army Natick Laboratories.
- Waldron, E. T., Smith, W. F., and Mahen, M. E. The protection provided by winter aviators' garments during escape through JP-4 fuel fires. Natick, MA: U.S. Army Natick Laboratories. In press.
- Weaver, J. A., and Stoll, A. M. 1969. Mathematical model of skin exposed to thermal radiation. Aerospace medicine. 40:24-30.
- Weinstein, G. D. 1966. Comparison of turnover time of keratinous protein fractions in swine and human epidermis. In: Bustad, K.L., and McClellan, R.O., eds. Swine in biomedical research. Seattle, WA: Frayn.
- Zilioli, A. E. 1971a. Crash injury economics: The costs of training and maintaining on Army aviator. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-17.
- 1971b. Crash injury economics: Aircrewman injury and death costs occurring in UH-1 Army aircraft accidents in fiscal year 1969. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-18.

Appendix A

ANALYTICAL MODEL

Several years ago Weaver and Stoll (1969) proposed an extension of Stoll's earlier model (Stoll and Greene, 1959) to heat fluxes higher than those used in obtaining the experimental data upon which the earlier model had been based. They also found that the effective conductivity changed during the exposure and subsequent cooldown period. Takata (1974), using preliminary data from USAARL's Thermal Project (the uncorrected version of the current data base), formulated a model which not only predicted threshold burns but deep burns and tissue water boiling as well. Building on the work of Henriques (1947), Stoll and Greene (1959), Weaver and Stoll (1969), Mehta and Wong (1973) and Takata (1974), an analytical model was formulated as follows:

For the thermal exposure of interest, skin is essentially opaque to thermal radiation and can be considered to transfer energy internally by conduction only, since exposure durations are no longer than the minimum response times reported for increased thermoregulatory system activity (1954). Consequently, thermal energy transfer in skin can be described by the heat conduction or Fourier equation be written as follows:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T}{\partial x} \right) + q \quad (1)$$

where,

ρ = density, gm/cm³

C_p = heat capacity, cal/gm-°C

K = thermal conductivity, cal/cm-sec-°C

T = temperature, °C

x = distance, cm

q = energy source, for the first nodal volume, cal/cm³-sec

¹Simplifying assumption base on the predominance of the radiate mode of heating. May be less valid with fabrics. In actuality a correction is made to q to account for convective heating, surface absorptivity, and attenuation of radiant heating by hair.

Since skin is considered to be opaque to radiant energy from a post crash fire, and since the source term is due only to radiant energy¹, equation (1) applies only to the surface of the skin. For all conditions in which $x > 0$, equation (1) reduces to the following:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T}{\partial x} \right) \quad (2)$$

Solution of equation (1) and (2) requires two boundary conditions for x , preferably at $x = 0$ and $x = L$, and initial conditions at $t = 0$ for all positions $0 < x < L$. If one assumes that there is no backward flux of thermal energy at $x = 0$ (all conduction is into the skin), then the energy flux at $x = 0$ is zero and, consequently, $\partial T / \partial x = 0$. Similarly, if the problem assumes that an adiabatic backwell condition prevails at $x = L$, the fatty tissue, then the net flux out of the system at $x = L$ is 0, or $\partial T / \partial x = 0$. These two boundary conditions indicate that the system is closed and that all thermal energy added to the system, $0 \leq x \leq L$, is distributed within the system and cannot escape.

Initial conditions are established by specifying a uniform temperature for all locations, $0 \leq x \leq L$ at time $t = 0$.

Consequently, the system may be defined by the following mathematical model:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T}{\partial x} \right) + q \quad @ x = 0 : \text{surface} \quad (3a)$$

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(K \frac{\partial T}{\partial x} \right) \quad @ 0 \leq x \leq L \quad (3b)$$

$$T_x = \text{CORE TEMPERATURE} = \text{TEMP10} + \text{TEMPB}$$

$$T = T_0, 0 \leq x \leq L, t = 0 \quad \text{Initial Conditions} \quad (4)$$

$$\frac{\partial T}{\partial x} = 0, x = 0, 0 \leq t \leq x \quad \text{Boundary Conditions 1} \quad (5)$$

$$\frac{\partial T}{\partial x} = 0, x = L, 0 \leq t \leq x \quad \text{Boundary Conditions 2} \quad (6)$$

Solution of mathematical model (Reneau and O'Young, 1976, 1977, 1978)

An analytical solution to equation set (3) was not considered feasible due to the variable nature of q , C_p and K , so explicit differencing methods of numerical analysis were employed to solve the equations. Several investigators working with linear systems have found that the Crank- Nicholson six point implicit differencing method provided an excellent numerical solution (Crank and Nicholson, 1947). For the solution of equation set (3) of the mathematical model, it was decided to apply the Crank-Nicholson method to the second order partial derivatives and corresponding explicit methods to the first order partials.

The grid work in Figure A-1 is a representative of the differenced system from $x = 0$ to $x = L$ (j 's) and $t = 0$ to $t = \tau$ (i 's).

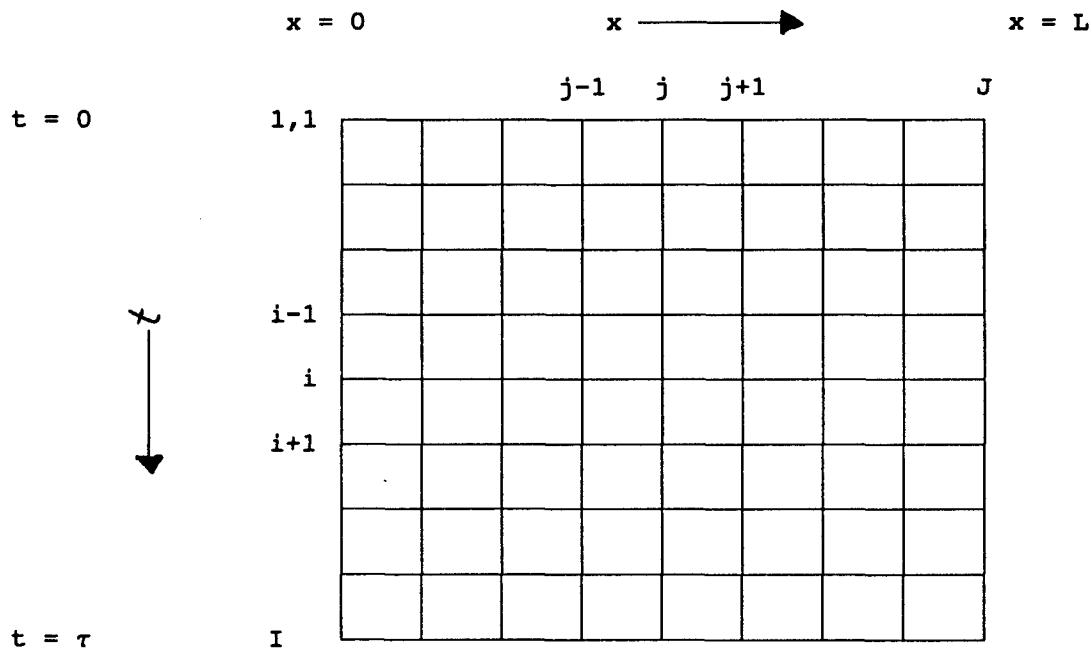


Figure A-1. Gridwork for numerical analysis

The Crank-Nicholson technique involves averaging the value of the dependent variable over the i and $i + 1$ row at a constant j position. The second order derivative is then evaluated at the $(j, i + 1/2)$ position. A forward difference formulation is applied to the term to match the same position.

The above described implicit differencing method is noted for the characteristics of stability and convergence. Correct increment sizes yield reliable convergence. The model was implemented in FORTRAN IV using solution techniques of Thomas as described by Bruce et al. (1953).

This initial model was revised to allow energy flux across the surface, $x = 0$, during heating, convective heat loss at the skin surface during cooling and heat transfer into deep tissues including conduction into fat, convective cooling via the blood, tissue water boiling, a temperature gradient from surface to fat and a gradient of thermal properties based on measured tissue water. The model, BURNSIM, is a run interactively with the following variables changeable for each run:

Table A-1
Model parameters changeable interactively

INPUTS

TEMPIO	=	Initial surface temperature, °C; nominally 32.5 °C for man
DENS	=	Density of skin, 1.0 gm/cm ³
Q1	=	Incident heat flux either constant or as a file of fluxes, cal/cm ² -sec
BL	=	Skin thickness, 2200μm (The last 200μm is considered to be fat)
AK	=	Calculation interval, nominally .01 sec. For short exposures, the calculation interval must be at least one hundred times less than the exposure duration.
JINC	=	Number of nodes, nominally 12
TEMPB	=	Differences between TEMPIO and backwall (fat/core) temperature, °C. Note: TEMPIO + TEMPB = core temperature
Absorb	=	Absorptivity usually 0.613 assuming 10 percent convective, 90 percent radiative heating, and 5 percent of radiation intercepted by hair
Boil	=	Temperature when water boiling occurs, 100.15 °C
ETIME	=	Exposure time, seconds
ITIME	=	Maximum calculation time, usually 80-100 seconds
Nxtra	=	Number of extra nodes between the surface and node #2 at 200μm, initially set at seven, used for superficial burns Note: The seventh node must be at 175μm for an accurate time to pain prediction.
Blood	=	Factor to adjust amount of convective cooling by blood usually set at 0.001

DE1 & DE2 = $\Delta E/R$ from Arrhenius relationship for tissue temperatures from 44°C to 50°C, or over 50°C, respectively

PL1, PLN1, or PL2 and PLN2 $\Rightarrow \log P = \log N + y \log 10 = PL + PLN$
for tissue temperatures from 44°C to 50°C, or over 50°C, respectively

Damage Rate Constants: PL1, PLN1, PL2, PLN2, DE1, DE2 (for Nodes 2-12)
APL1, APLN1, APL2, APLN2, ADE1, ADE2 (for Nodes 1 and Xtra Nodes)

Cp(J) = Heat capacity as a function of depth, (J)

BK(J) = Thermal conductivity as a function of depth, (J)

PCWATER = Percent water at a skin depth of 10 μ m at 60 percent relative humidity

WATER(J) = Percent water at each node based on 60 percent relative humidity

OUTPUTS

Flux (I) - tabulated heat flux as a function of time

DAMAGE, W, at each depth (Node)

Maximum temperature

Threshold depth in μ m (microns)

Final time - total calculation time

Time to pain

File of calculated temperatures for later plotting by HARVARD GRAPHICS

File summarizing simulation

File of temperature as printed each second on the terminal

From the relationship for first order kinetics assumed to apply in damaging tissue protein we have:

$$\text{damage rate} = \frac{dQ}{dt} = P e^{-\Delta E/RT};$$

$$\begin{aligned} \text{total} &= \int_0^{\text{ETIME}} \frac{d\Omega}{dt} + \int_{\text{ETIME}}^{\text{ITIME}} \frac{d\Omega}{dt} \\ \text{damage} & \quad \quad \quad 0 \quad \quad \quad \text{ETIME} \end{aligned} \quad (8)$$

if $P = N \times 10^y$ and $\Delta E/R = DE$

then:

$$\ln \frac{dw}{dt} = \ln N + y \ln 10 - \frac{\Delta E}{R} \cdot \frac{1}{T} = PL + PLN - DE \cdot \frac{1}{(T+273)} \quad (9)$$

Thus for damage calculations the following constants are entered:

$$PL_1 (44^\circ\text{C} - 50^\circ\text{C}) = 1.46$$

$$PL_2 (50^\circ\text{C} - 100^\circ\text{C}) = 2.24$$

$$PLN_1 (44^\circ\text{C} - 50^\circ\text{C}) = 147.37$$

$$PLN_2 (50^\circ\text{C} - 100^\circ\text{C}) = 239.47$$

$$DE_1 (44^\circ\text{C} - 50^\circ\text{C}) = 50,000$$

$$DE_2 (50^\circ\text{C} - 100^\circ\text{C}) = 80,000$$

The program outputs $d\Omega/dt$, for each node at each time step, total is damage for each node and a threshold depth, where $\Omega = 1$. This depth, found using inverse interpolation on two or three Ω s nearest 1 using either y or $\log(y)$.

Since the first presentations (Knox, Wachtel, and Knapp, 1978a, 1978c) BURNSIM has under gone further development.

Thermal properties of skin

Measurements of the water content of pig skin as a function of thickness were made on split thickness skin samples from several pigs.

Give a table of measured values of water content as a function of skin thickness, a least-square cubic polynomial was fit to the data and water content as a function of depth was computed from the formula:

$$W(T-d) = \frac{T}{d}(W_T - W_{T-d}) + W_{T-d} \quad (10)$$

where T is the total thickness of a slab, W_T is the fraction of water computed from the cubic equation, d is the thickness of a thin slab at a depth $T-d$, and W_{T-d} is the fraction of water above the thin slab.

Thermal properties of the tissue were computed from the equations (Cooper and Trezek, 1971):

$$1) \text{ density: } \gamma = \left[\frac{W_w}{\gamma_w} + \frac{W_f}{\gamma_f} + \frac{W_p}{\gamma_p} \right]^{-1} \quad (11)$$

$$2) \text{ heat capacity: } Cp = W_w Cp_w + W_f Cp_f + W_p Cp_p \quad (12)$$

$$3) \text{ thermal conductivity: } K = \gamma \left[\frac{k_w W_w}{\gamma_w} + \frac{k_f W_f}{\gamma_f} + \frac{k_p W_p}{\gamma_p} \right] \quad (13)$$

where the subscripts w, f, and p refer to water, fat, and protein, respectively. W_n is the mass fraction, γ_n the density, Cp_n the heat capacity, and k_n the thermal conductivity of the respective components. Values of the various terms used were:

$$\gamma_w = 1 \text{ gm/cm}^3 \quad Cp_w = 1 \text{ cal/gm-}^\circ\text{C} \quad k_w = 1.5 \times 10^{-3} \text{ cal/cm-sec-}^\circ\text{C}$$

$$\gamma_f = 0.815 \text{ gm/cm}^3 \quad Cp_f = 0.55 \text{ cal/gm-}^\circ\text{C} \quad k_f = 4.5 \times 10^{-4} \text{ cal/cm-sec-}^\circ\text{C}$$

$$\gamma_p = 1.54 \text{ gm/cm}^3 \quad Cp_p = 0.26 \text{ cal/gm-}^\circ\text{C} \quad k_p = 4.3 \times 10^{-4} \text{ cal/cm-sec-}^\circ\text{C}$$

Fat and protein were assumed to be present in equal amounts so that:

$$W_f = W_p = (1 - W_w) / 2, \quad (14)$$

and the resultant equations were:

$$\gamma = (6.18277 \times 10^{-2} W_w + .938172)^{-1} \quad (15)$$

$$K = \gamma (1.08432 \times 10^{-3} W_w + 4.15684 \times 10^{-4}) \quad (16)$$

$$Cp = .595 W_w + .405 \quad (17)$$

Using the equations above, the profile of thermal properties was calculated for skin depths of from 80 to 2000 μm . A linear extrapolation of tissue water content from a depth of 80 μm to the skin surface was made using a stratum corneum water content calculated from Rushmer et al. (1966) and the ambient percent humidity during the experimental phase of the project. This calculated water profile was used to complete the calculation of thermal properties profile from 80 μm to the skin surface. The thermal properties of the skin at 2200 μm were assumed to be those of fat. These new thermal properties replaced those chosen by Morse et al. (1973) and used during previously reported simulations (Knox, Wachtel, and Knapp, 1978a, 1978c). See the paper entitled "Thermal properties calculated from measured water content as a function of depth in porcine skin" (Knox et al., 1986).

Intraskin temperatures

In earlier simulations (Knox et al, 1978a, 1978c) it became apparent that unless the temperature calculations reasonably represented what actually occurred in the skin, adjustment of the values for PL, PLN and DE in the damage equation to match a few data points would not be likely to result in a model which works well for all cases. Fortunately

11 intraskin temperature profiles were recorded on FM magnetic tape. These voltage records were digitized and converted to tables of temperatures at 100 samples per second. Figure A-2 presents the one page summary report from a simulation of the exposure of Pig 294RF to a 3.47 cal /cm²-sec fire for 3.02 seconds. Note that boiling occurred (confirmed by blister formation, Figure A-3) and that the surface reached a maximum of 128.724°C. Predicted threshold depth was 1520μm. Three observed temperature profiles are overlayed on the calculated temperature profiles (for nodal depths of 0, 200, 400....2200μm) in Figures A-4, A-5, and A-6. The oscillations in the observed temperature profile are most probably due to a "hunting" in the autoregulation of tissue perfusion by blood. The frequency, for example, is similar to that seen in studies of microcirculation.

MODEL NAME OR DESCRIPTION: FIG 294RF ABS 0.613

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO= 34.9700	DENS= 1.00000	Q1= 3.47000
BL= .220000	AK= .100000E-01	JINC= 12
TEMPB= 3.3600	ABSORB= .613000	BOIL= 100.150
APL1= .780000	APLN1= 285.520	ADE1= 93534.9
APL2= .600000	APLN2= 117.430	ADE2= 39109.8
PL1= 1.46	PLN1= 147.37	DE1= 50000.00
PL2= 2.24	PLN2= 239.47	DE2= 80000.00
ETIME= 3.02	ITIME= 80.00	NXTRA= 8
BLOOD= .0010		

EXTRA NODES: 22.2 44.4 66.7 88.9 111.1 133.3 155.6 177.8

FLUX FILE I.D.: .00 2

FLUX(I)=
1 3.470 2 3.470

W= .39950E+01
W= .40733E+00
W= .45290E-01

D= .72442E+01
D= .73778E+01
D= .74955E+01

W = .19755E+19	AT DEPTH (IN MICRONS)=	.112535E-06
W = .82482E+12	AT DEPTH (IN MICRONS)=	200.000
W = .26532E+09	AT DEPTH (IN MICRONS)=	400.000
W = .57713E+06	AT DEPTH (IN MICRONS)=	600.000
W = .84775E+04	AT DEPTH (IN MICRONS)=	800.000
W = .44473E+03	AT DEPTH (IN MICRONS)=	1000.00
W = .39319E+02	AT DEPTH (IN MICRONS)=	1200.00
W = .39950E+01	AT DEPTH (IN MICRONS)=	1400.00
W = .40733E+00	AT DEPTH (IN MICRONS)=	1600.00
W = .45290E-01	AT DEPTH (IN MICRONS)=	1800.00
W = .89902E-02	AT DEPTH (IN MICRONS)=	2000.00
W = .00000E+00	AT DEPTH (IN MICRONS)=	2200.00

MAXIMUM TEMPERATURE = 128.724

THRESHOLD DEPTH = 1528.

FINAL TIME = 80.00

Figure A-2. Summary report for simulation of Fig 294RF to a 3.47 cal/cm²-sec fire for 3.02 seconds.

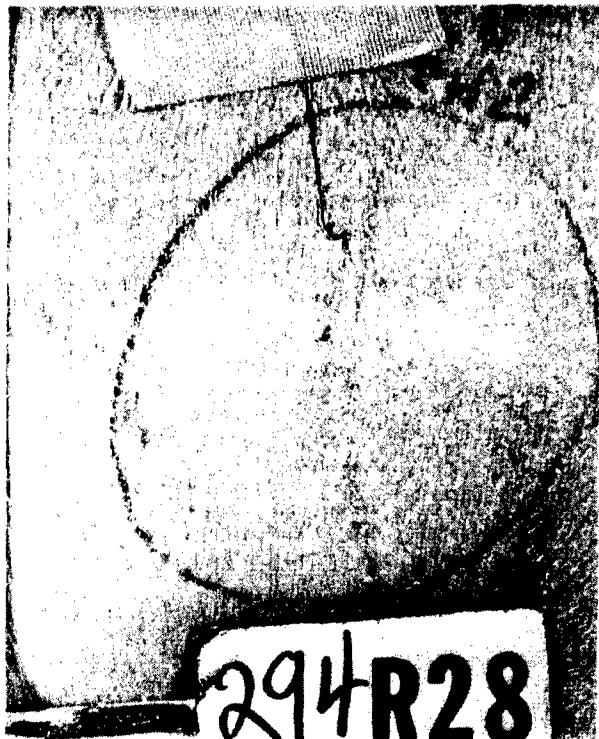


Figure A-3. Intraskin thermocouple (0.003", "located superficially") shown prior to burn (left) and subsequent to exposure to $3.47 \text{ cal} \cdot \text{cm}^{-2} \cdot \text{sec}^{-1}$ for 3.02 seconds (right).

Gross grade = 13

New micro grade = 8

Threshold depth = $1465 \mu\text{m}$

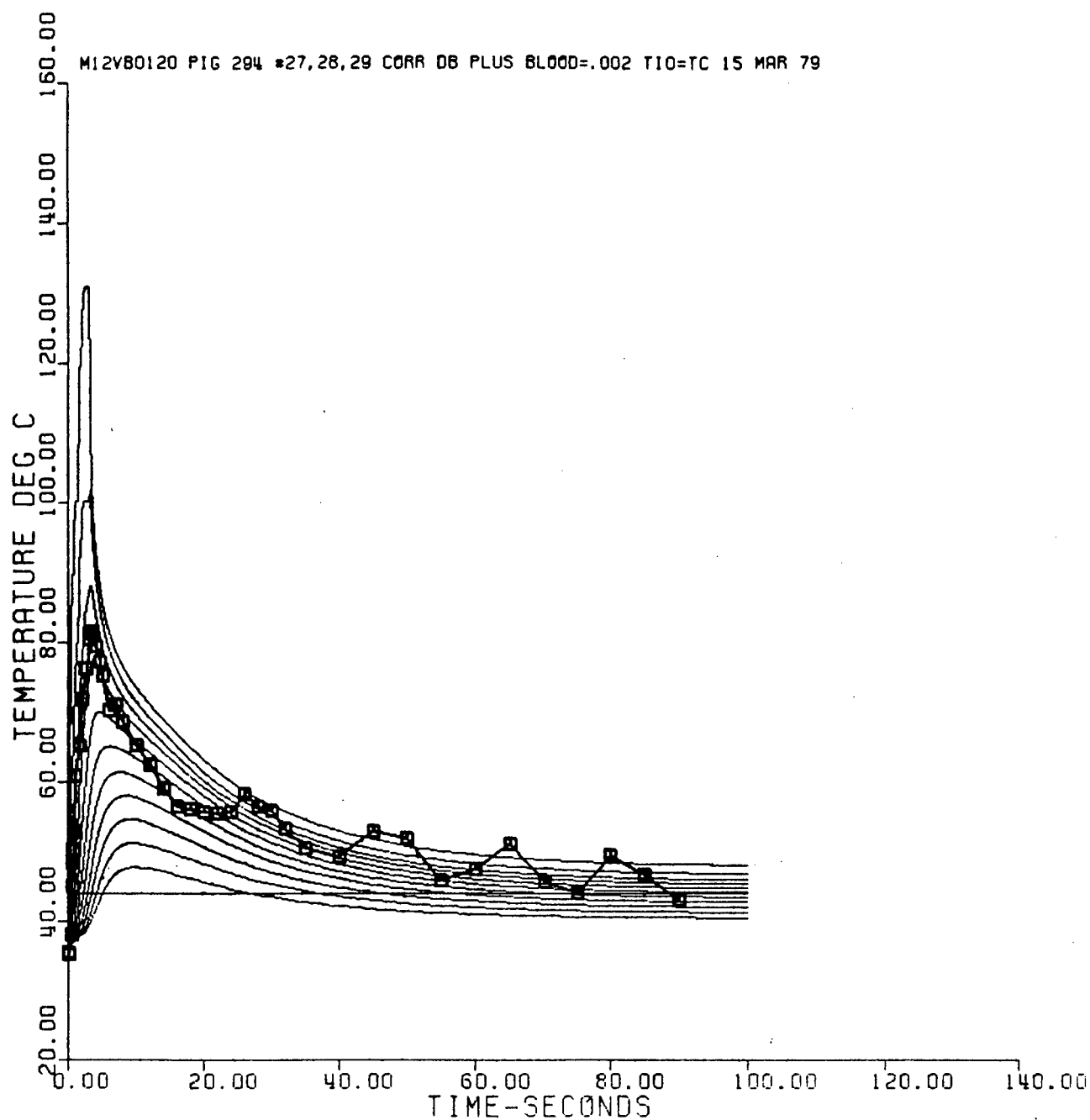


Figure A-4. Predicted skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #27 when exposed to $3.47 \text{ cal.cm}^{-2}.\text{sec}^{-1}$ for 3.02 seconds

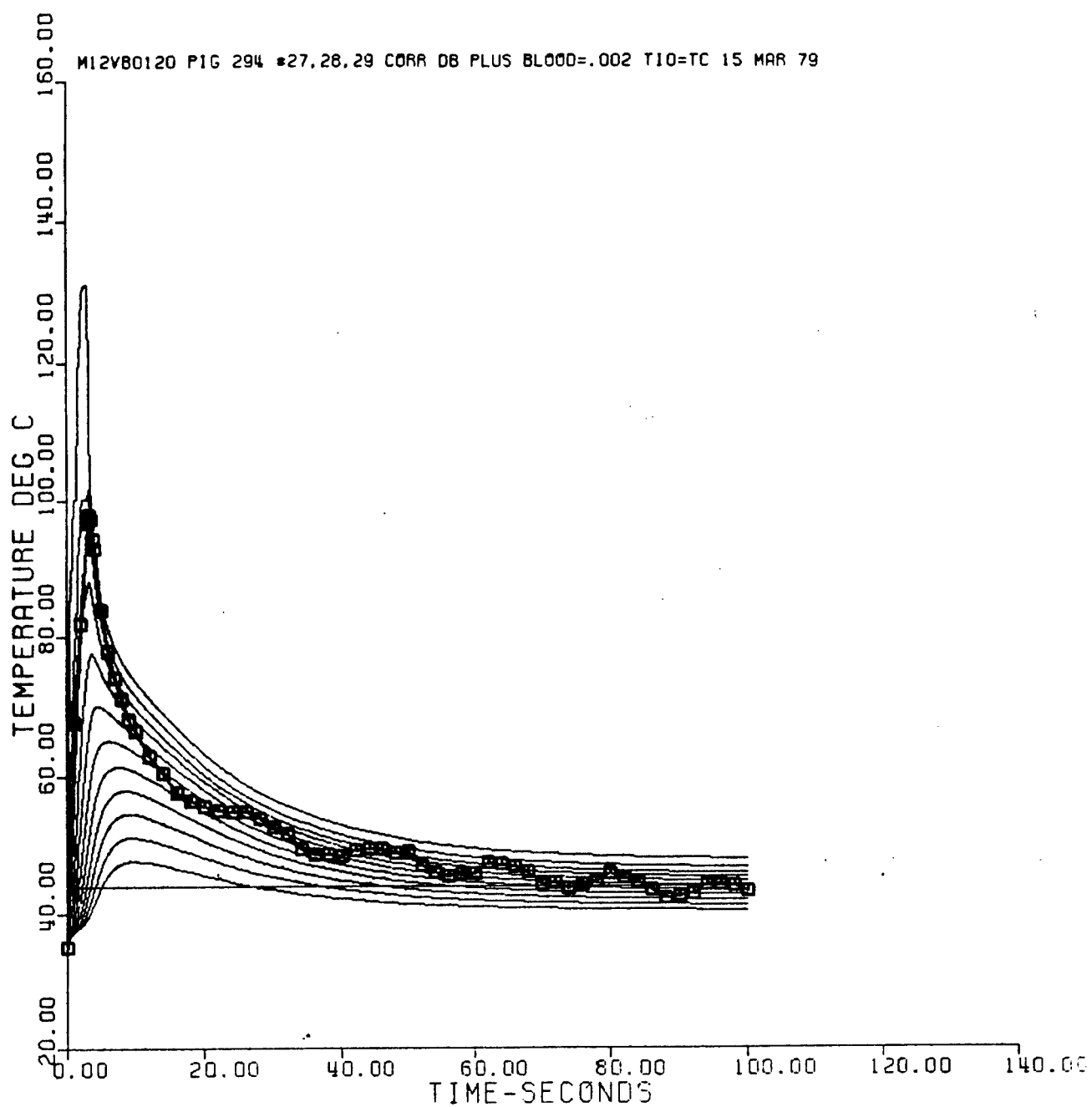


Figure A-5. Predicated skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #28 when exposed to $3.47 \text{ cal}\cdot\text{cm}^{-2}\cdot\text{sec}^{-1}$ for 3.02 seconds

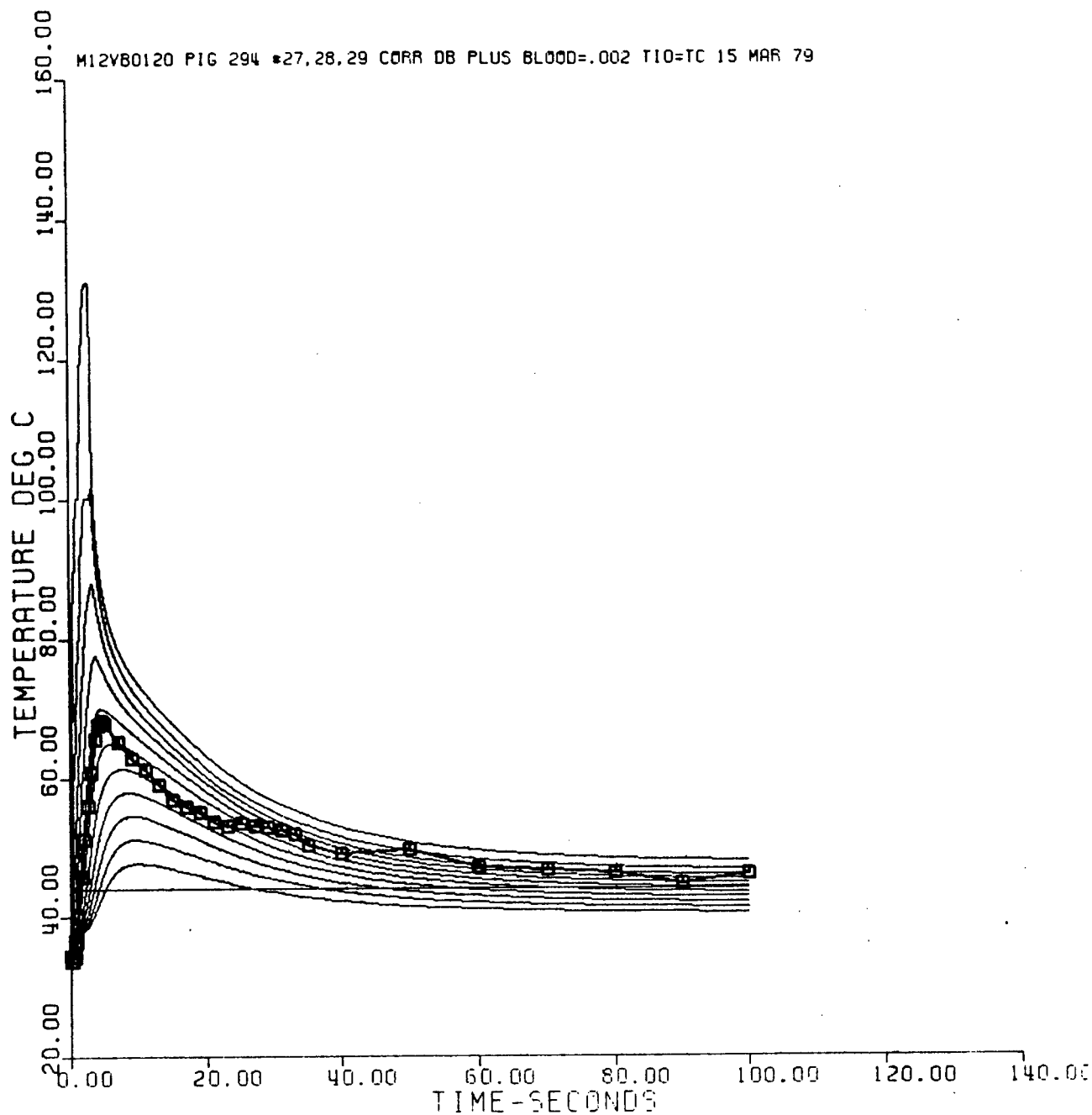


Figure A-6. Predicated skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #29 when exposed to $3.47 \text{ cal}\cdot\text{cm}^{-2}\cdot\text{sec}^{-1}$ for 3.02 seconds

APPENDIX B

C Last Edited March 5, 1992
C ***** 12-POINT BURN PREDICTION MODEL*****

C PROGRAM BURNSIM ! BURN PREDICTION MODEL WITH WATER BOILING
C ! AND USE OF EITHER CONSTANT OR TABULATED FLUX
C ! AND VARIABLE COOLING BY BLOOD FROM NODES 2
C ! AND 3 BEGINNING AT .01 SEC AND LINEARLY
C ! INCREASING TO 20 SEC AND THEN REMAINING
C ! CONSTANT.....

C ! CHANGED TO DO INTEGRATION OF DAMAGE W & XW
C ! WITHIN PROGRAM AND NOT OUT TO DISK AND BACK

C ! CHANGED TO INCORPORATE THE CHANGES IN MODEL
C ! 7 NAMELY DIFFERENT RATE CONSTANTS ETC FOR
C ! SUPERFICIAL NODES AND VARIABLE AK IN BLUD

C THIS MODEL WAS DEVELOPED UNDER CONTRACT FOR THE U.S. ARMY
C MEDICAL RESEARCH AND DEVELOPMENT COMMAND, AND THE U.S. ARMY
C AEROMEDICAL RESEARCH LABORATORY, FORT RUCKER AL. 36362,
C STANLEY C. KNAPP, COL, MC, COMMANDING, BY FRANCIS S. KNOX, III,
C PH.D. WITH THE ASSISTANCE OF DANIEL D. RENEAU, PH.D., NELSON
C O'YOUNG, AND CHET ELLIS, M.S.

C ADDITIONAL DEVELOPMENT CONDUCTED UNDER ILIR FUNDING AT USAARL
C AND ON OWN TIME BY FRANCIS S. KNOX, III, PH.D.

C QUESTIONS AND COMMENTS SHOULD BE ADDRESSED TO:

C FRANCIS S. KNOX, III, PH.D
C CHIEF, ESCAPE AND IMPACT PROTECTION BRANCH
C BIODYNAMICS AND BIOCOMMUNICATIONS DIVISION
C ARMSTRONG LABORATORY
C WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433
C COM. 513-255-3931 AV 785-3931

C This copy current working copy of Dr. Knox. Other copies
C are not to be further distributed without permission from
C Dr. Knox.
C.....

 INCLUDE 'FGRAPH.FI'
 INCLUDE 'FGRAPH.FD'
 REAL*4 ITIME,NOFIL,TP,SUM(13),DW(13)
 INTEGER CHANGE,PTS,AGAIN,PROCED
 INTEGER*4 DUMMY4
 INTEGER*2 DUMMY2
 DIMENSION T(12),F(12),G(12),H(12),W(12),Z(12),SV(12),U(12)
 DIMENSION CP(12,2),BK(12,2),D(12),DSCRPT(20)
 DIMENSION ID(4),FLUX(600),Q(12)

```

DIMENSION XTIME(12),ZTIME(12),IFLAG(12),JFLAG(12)
DIMENSION WATER(12,2),ROCON(2),THCON(2),CPCON(2)
DIMENSION XW(8),XTRA(8),XTRALG(8),XTMP(8),XDW(8),XSUM(8)
CHARACTER RESP*1,FILNAM*8,SUMFILE*8,PROFILE*8,TFILE*8
EQUIVALENCE (NOFIL,IBLNK)
  DATA NOFIL/' '/
  DATA MAXDIM/12/,D2/200./
  DATA THCON/1.084316E-3,4.1568401E-4/
  DATA ROCON/6.1827743E-2,0.93817226/
  DATA CPCON/0.595,0.405/

C      LOGICAL UNIT 1 INPUT  : 'REN12.DAT'; INITIAL VALUES OF PARAMETERS
C      LOGICAL UNIT 1 SCRATCH: VALUES OF XW (IF COMPUTED)
C      LOGICAL UNIT 2 SCRATCH: VALUES OF W (COMPUTED)
C      LOGICAL UNIT 3 OUTPUT  : PROFILE; TEMPERATURE PROFILES
C      LOGICAL UNIT 4 INPUT   : FILNAM; NAME OF FLUX FILE
C      LOGICAL UNIT 4 OUTPUT  : TFILE; DATA FOR PLOTTING TEMPERATURE
C                               PROFILES
C      LOGICAL UNIT 7 OUTPUT  : SUMMARY PRINTOUT

C*****Introduction to BURNSIM
  CALL COLORS
  DUMMY4=SETBKCOLOR( $BLUE )
  CALL WELCOME(PROFILE)
C*****Read REN12.DAT input file
  CALL READDATA(TEMP10,DENS,Q0,BL,AK,BOIL,ABSORB,JINC,TEMPB,
+ ITIME,ETIME,PCWATR,BLOOD,CP,BK,PL2,PLN2,PL1,PLN1,DE2,DE1,
+ APL1,APLN1,APL2,APLN2,ADE1,ADE2,WATER)
  OPEN(UNIT=1,FORM='UNFORMATTED',STATUS='SCRATCH')
  OPEN(UNIT=2,FORM='UNFORMATTED',STATUS='SCRATCH')
  OPEN(UNIT=3,FILE=PROFILE,FORM='FORMATTED',STATUS='UNKNOWN')
  FLUX(1) = Q0
  FLUX(2) = Q0
  NFLX = 2
  FILNAM = NOFIL
  PPL1 = PL1
  PPLN1 = PLN1
  DDE1 = DE1
  APPL1 = APL1
  APPLN1 = APLN1
  ADDE1 = ADE1
  NXTRA = 0
  NXTRA0 = NXTRA
C*****Display input values on screen
  CALL SHOWVALUE(TEMP10,DENS,FLUX,BL,AK,JINC,TEMPB,
+ ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
+ BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
  DO WHILE (AGAIN .EQ. 0)
    CALL PROCEED(RESP,PROCEED,AGAIN)
    IF(PROCEED.EQ.0) THEN
      PTS=1
      TIME=0.

```

```

CHANGE=0
MN=0
CALL clearscreen( $GCLEARSCREEN )
WRITE(*,10)
10  FORMAT(//,15X,'TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU',/
+ ,15X,'WISH TO PERFORM.',////,20X,'CHOOSE A FUNCTION NUMBER: ',/,
+ 25X,'1 - CHANGE SELECTED INITIAL VALUES',/,25X,'2 - NO CHANGES',
+ '--CONTINUE RUNNING THE PROGRAM',/,25X,'3 - EXIT',//,20X,'PLEASE'
+ ' ENTER THE FUNCTION NUMBER: '$)
    READ(*,20) IANSR
20  FORMAT(I2)
    CALL clearscreen( $GCLEARSCREEN )
    IF(IANSR.EQ.1) THEN
        DOWHILE(CHANGE.EQ.0)
            CALL SHOWVALUE(TEMP10,DENS,FLUX,BL,AK,JINC,TEMPB,
+ ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
+ BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
            WRITE(*,30)
30  FORMAT(///,15X,'DO YOU WANT TO MAKE ANY CHANGES? TYPE Y/N '$)
            READ(*,40) RESP
40  FORMAT(A1)
            IF(RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
                CALL CLEARSCREEN( $GCLEARSCREEN )
                WRITE(*,50)
50  FORMAT(/T5,'PICK A NUMBER',//T10,'1=TEMP10',T30,'8=ETIME',//
+ T10,'2=DENS',T30,'9=PL1',/T10,'3=Q1',T30,'10=PLN1',//
+ T10,'4=BL',T30,'11=PL2',/T10,'5=AK',T30,'12=PLN2',//
+ T10,'6=JINC',T30,'13=DE1',/T10,'7=TEMPB',T30,'14=DE2',//
+ T10,'15=ETIME',T30,'16=ABSORBTIVITY'//
+ T10,'17=BOIL',T30,'18=EXTRA NODES'//
+ T10,'19=BLOOD',T30,'20=APL1'//
+ T10,'21=APLN1',T30,'22=APL2'//
+ T10,'23=APLN2',T30,'24=ADE1',T55,'25=ADE2',/,9X,$)
                READ(*,20) INUM
                IF(INUM.EQ.1) THEN
                    WRITE(*,60) TEMP10
60  FORMAT(//,9X,'THE VALUE FOR TEMP10 IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
                    READ(*,70) TEMP10
70  FORMAT(G10.5)
                    ELSEIF(INUM.EQ.2) THEN
                        WRITE(*,80) DENS
80  FORMAT(//,9X,'THE VALUE FOR DENS IS: ',F10.5,' INPUT NEW VALUE: '
+ '$)
                        READ(*,70) DENS
                        ELSEIF(INUM.EQ.3) THEN
                            WRITE(*,90)
90  FORMAT(//,9X,'ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE '
+ ',,9X,'IS TO BE USED): '$)
                            READ(*,100) FILNAM
100  FORMAT(A8)
C*****Read in flux file

```

```

        IF (FILNAM.NE.NOFIL) THEN
            WRITE(*,110)
110     FORMAT(/,9X,'ENTER FLUX ID (UP TO 8 CHARACTERS): '$)
            READ(*,120)
120     FORMAT(4A2)
            WRITE(*,130)
130     FORMAT(/,9X,'ENTER THE NUMBER OF POINTS IN FLUX FILE: '$)
            READ(*,*) NFLX
            DO WHILE (NFLX .GT. 600)
                WRITE(*,140)
140     FORMAT(/,9X,'THE FLUX FILE MUST CONTAIN NO MORE THAN 600 DATA'
+ ,/,9X,'POINTS. REENTER A NUMBER LESS THAN OR EQUAL TO 600. '$)
                READ(*,*) NFLX
            END DO
            WRITE(*,150)
150     FORMAT(/,9X,'ENTER THE SAMPLE INTERVAL IN SECONDS: '$)
            READ(*,*) TDELT
            OPEN(UNIT=4,FILE=FILNAM,FORM='FORMATTED',STATUS=
+ 'OLD')
            READ(4,*) (FLUX(I),I=1,NFLX)
            CLOSE (4)
            IF(NFLX.LE.0) STOP 'ERROR----TOO FEW FLUX POINTS.'
            WRITE(*,430)ID,TDELT,NFLX
            ELSE
                WRITE(*,160)FLUX(1)
160     FORMAT(//,9X,'CONSTANT Q-VALUE = ',F10.5,' INPUT NEW VALUE: '
+ $)
                READ(*,70)FLUX(1)
                FLUX(2)=FLUX(1)
                NFLX = 2
                DO I=1,4
                    ID(I) = IBLNK
                END DO
            END IF
            ELSEIF(INUM.EQ.4) THEN
                WRITE(*,170)BL
170     FORMAT(//,9X,'THE VALUE FOR BL IS: ',F10.5,' INPUT NEW VALUE: '
+ $)
                READ(*,70)BL
                ELSEIF(INUM.EQ.5) THEN
                    WRITE(*,180)AK
180     FORMAT(//,9X,'THE VALUE FOR AK IS: ',F10.5,' INPUT NEW VALUE: '
+ $)
                    READ(*,70)AK
                    ELSEIF(INUM.EQ.6) THEN
                        WRITE(*,190)JINC
190     FORMAT(//,9X,'THE VALUE FOR JINC IS: ',I30,' INPUT NEW VALUE: '
+ $)
                        READ(*,20)JINC
                        IF (JINC.GT.MAXDIM) JINC=MAXDIM
                        ELSEIF(INUM.EQ.7) THEN
                            WRITE(*,200)TEMPB

```

```

200  FORMAT (//,9X,'THE VALUE FOR TEMPB IS: ',F10.5,' INPUT NEW VA'
+ 'LUE: '$)
      READ(*,70)TEMPB
      ELSEIF(INUM.EQ.8) THEN
      WRITE(*,210)ETIME
210  FORMAT(//,9X,'THE VALUE FOR ETIME IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
      READ(*,70)ETIME
      ELSEIF(INUM.EQ.9) THEN
      WRITE(*,220)PL1
220  FORMAT(//,9X,'THE VALUE FOR PL1 IS: ',F10.5,' INPUT NEW VALUE'
+ ': '$)
      READ(*,70)PL1
      PPL1=PL1
      ELSEIF(INUM.EQ.10) THEN
      WRITE(*,230)PLN1
230  FORMAT(//,9X,'THE VALUE FOR PLN1 IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
      READ(*,70)PLN1
      PPLN1=PLN1
      ELSEIF(INUM.EQ.11) THEN
      WRITE(*,240)PL2
240  FORMAT(//,9X,'THE VALUE FOR PL2 IS: ',F10.5,' INPUT NEW VALUE'
+ ': '$)
      READ(*,70)PL2
      ELSEIF(INUM.EQ.12) THEN
      WRITE(*,250)PLN2
250  FORMAT(//,9X,'THE VALUE FOR PLN2 IS: ',F10.5,' INPUT NEW VALUE'
+ ': '$)
      READ(*,70)PLN2
      ELSEIF(INUM.EQ.13) THEN
      WRITE(*,260)DE1
260  FORMAT(//,9X,'THE VALUE FOR DE1 IS: ',F10.1,' INPUT NEW VALUE'
+ ': '$)
      READ(*,70)DE1
      DDE1=DE1
      ELSEIF(INUM.EQ.14) THEN
      WRITE(*,270)DE2
270  FORMAT(//,9X,'THE VALUE FOR DE2 IS: ',F10.1,' INPUT NEW VALUE'
+ ': '$)
      READ(*,70)DE2
      ELSEIF(INUM.EQ.15) THEN
      WRITE(*,280)ITIME
280  FORMAT(//,9X,'THE VALUE FOR ITIME IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
      READ(*,70)ITIME
      ELSEIF(INUM.EQ.16) THEN
      WRITE(*,290)ABSORB
290  FORMAT(//,9X,'THE VALUE FOR ABSORB IS: ',F10.5,' INPUT NEW VAL'
+ 'UE: '$)
      READ(*,70)ABSORB
      ELSEIF(INUM.EQ.17) THEN

```

```

        WRITE(*,300)BOIL
300    FORMAT(//,9X,'THE VALUE FOR BOIL IS: ',F10.5,' INPUT NEW VALUE'
+ ': '$)
        READ(*,70)BOIL
        ELSEIF(INUM.EQ.18) THEN
            NXTRAO = NXTRA
            WRITE(*,310)NXTRA
310    FORMAT(//,9X,'THE NUMBER OF EXTRA NODES IS: ',I4,' INPUT NEW'
+ ' VALUE: '$)
            READ(*,20)NXTRA
            IF (NXTRA.NE.0) THEN
                IF (NXTRA.GT.8) NXTRA=8
                IF (NXTRAO.NE.0) WRITE(*,320) (XTRA(I),I=1,NXTRAO)
320    FORMAT(/,9X,'CURRENT EXTRA NODES: ',8F6.1)
                WRITE(*,330)
330    FORMAT(//,9X,'ENTER NEW VALUES SEPARATED BY COMMAS, OR A <CR> '
+ ',/,9X,'IF THE PROGRAM IS TO CALCULATE VALUES. '$)
                READ(*,340)XTRA
340    FORMAT(8G6.1)
                IF (XTRA(1).LE.0) THEN
C*****Numerator in next statement is specific for n-point model
                DXTRA = D2/(NXTRA+1)
                DO I=1,NXTRA
                    XTRA(I) = DXTRA*I
                END DO
                END IF
                DO I=1,NXTRA
                    XTRALG(I) = ALOG(XTRA(I))
                END DO
                END IF
                NXTRAO = NXTRA
                ELSEIF(INUM.EQ.19) THEN
                    WRITE(*,350)BLOOD
350    FORMAT(//,9X,'THE VALUE FOR BLOOD IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
                    READ(*,70)BLOOD
                    ELSEIF(INUM.EQ.20) THEN
                        WRITE(*,360)APL1
360    FORMAT(//,9X,'THE VALUE FOR APL1 IS: ',F10.5,' INPUT NEW VALUE'
+ ': '$)
                        READ(*,70)APL1
                        ELSEIF(INUM.EQ.21) THEN
                            WRITE(*,370)APLN1
370    FORMAT(//,9X,'THE VALUE FOR APLN1 IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
                            READ(*,70)APLN1
                            ELSEIF(INUM.EQ.22) THEN
                                WRITE(*,380)APL2
380    FORMAT(//,9X,'THE VALUE FOR APL2 IS: ',F10.5,' INPUT NEW VALUE'
+ ': '$)
                                READ(*,70)APL2
                                ELSEIF(INUM.EQ.23) THEN

```



```

        WRITE(*,390)APLN2
390    FORMAT(//,9X,'THE VALUE FOR APLN2 IS: ',F10.5,' INPUT NEW VALU'
+ 'E: '$)
        READ(*,70)APLN2
        ELSEIF(INUM.EQ.24) THEN
            WRITE(*,400)ADE1
400    FORMAT(//,9X,'THE VALUE FOR ADE1 IS: ',F10.1,' INPUT NEW VALUE'
+ ': '$)
            READ(*,70)ADE1
            ELSEIF(INUM.EQ.25) THEN
                WRITE(*,410)ADE2
410    FORMAT(//,9X,'THE VALUE FOR ADE2 IS: ',F10.1,' INPUT NEW VALUE'
+ ': '$)
                READ(*,70)ADE2
            ELSE
                CHANGE=1
            ENDIF
        ELSE
            CHANGE=1
        END IF
    END DO
    REWIND 1
    ELSEIF(IANSR.EQ.2) THEN
        CALL CLEARSCREEN( $GCLEARSCREEN )
        CALL DESCRIPT(DSCRIPT,SUMFILE,TFILE)
        TP=999.
        AJ=JINC
        Q1 = FLUX(1)
        H1=BL/(AJ-1.0)
C*****Initialize depth nodes D(J)
        D(1) = -16.
        DO I=2,JINC
            D(I) = H1*(I-1)*1.E4
            D(I) = ALOG(D(I))
        END DO
        DTJ = TEMPB/(JINC-1)
        DO J=1,JINC
            WATER(J,1) = WATER(J,2)
            CP(J,1) = CP(J,2)
            BK(J,1) = BK(J,2)
            XTIME(J) =0.
            ZTIME(J) =0.
            IFLAG(J) =0.
            JFLAG(J) =0.
            T(J) = DTJ*(J-1)+TEMPIO
        END DO
        WRITE(4,420)TIME,T(1),T(2),T(3),T(4),T(5),T(6),T(7),T(8)
+ ,T(9),T(10),T(11),T(12)
420    FORMAT(13(F9.5,2X))
        K=1
        CALL SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,ABSORB,
+ BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD,APL1,

```

```

+ APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
  WRITE(3,430)ID,TDELT,NFLX,(I,FLUX(I),I=1,NFLX)
  WRITE(7,430)ID,TDELT,NFLX,(I,FLUX(I),I=1,NFLX)
430  FORMAT(/,9X,'FLUX FILE I.D.: ',4A2,F7.2,I4:/' FLUX(I)='
+ /(' ',10(I5,F8.3)))
  JJJJ=0
  F(1)=-BK(2,1)/(2.0*H1*H1)-BK(1,1)/(2.0*H1*H1)
  G(1) = (BK(1,1)+BK(2,1))/(2.0*H1*H1)+DENS*CP(1,1)/AK
  H(1)=0.0
  ITTR = 0
  IFLX = 1
  EITIM1 = ITIME+1.
  IF (FILNAM.EQ.NOFIL) TDELT=AK
  FFDG = TDELT/AK
  KFDG = FFDG+.0001
  TMPMAX = 0.
  QCONST = ABSORB*60.892
  BLUD = 0.
  M = -1
  TIME = 0.
  ITFLG = 0
  CALL SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
  DOWHILE(TIME.LT.ITIME.AND.ITFLG.EQ.0.OR.TIME.LT.ETIME)
C*****The next program statement automatically chooses the proper
C      interval in the flux table for the computation of QT and Q1 for
C      either constant or variable flux.
C          KFDG (=FFDG) = 1 for constant flux
C                      = integer ratio of the tabular time step to
C                      to model the time step for the tabulated flux
  IF (MOD(ITTR,KFDG).EQ.0.AND.IFLX.LT.NFLX) IFLX=IFLX+1
  ITTR = ITTR+1
  P = (ITTR-KFDG*(IFLX-2))/FFDG
  QT = (1.-P)*FLUX(IFLX-1)+P*FLUX(IFLX)
  Q1 = QT*QCONST
  JJJJ = JJJJ+1
  TIME=JJJJ*AK
  IF (TIME.GE..01.AND.TIME.LE.20.) BLUD=(TIME-AK)/(20.-AK)*
+ BLOOD
  IF(TIME.GE.ETIME) Q1=-5.E-4*(T(1)-23.9)
  Z(1)=-F(1)*T(2)-((BK(1,1)+BK(2,1))/(2.0*H1*H1)-(DENS*
+CP(1,1))/AK)*T(1)+Q1
  N=JINC-1
  DO J=2,N
    F(J)=-BK(J+1,1)/(2.0*H1*H1)
    G(J)=(BK(J,1)+BK(J+1,1))/(2.0*H1*H1)+DENS*CP(J,1)/AK
    H(J)=-BK(J,1)/(2.0*H1*H1)
    Z(J)=-F(J)*T(J+1)-((BK(J,1)+BK(J+1,1))/(2.*H1*H1)-DENS
+ *CP(J,1)/AK)*T(J)-H(J)*T(J-1)
    IF (J.LE.3) Z(J) = Z(J)-1.675*H1/BK(J,1)*BLUD*(T(J)
+ -TEMPIO+TEMPB)
  END DO
  F(JINC)=0.0

```

```

      G(JINC)=(BK(JINC,1)+BK(JINC-1,1))/(2.0*H1*H1)+DENS*
+ CP(JINC,1)/AK
      H(JINC)=-(BK(JINC,1)+BK(JINC-1,1))/(2.0*H1*H1)
      DT=T(JINC-1)-(TEMPIO+TEMPB)
      Z(JINC)=(H(JINC)+(DENS*CP(JINC,1)/AK))*T(JINC)-H(JINC)*
+ T(JINC-1)-BK(JINC,1)*DT/H1**2
      W(1)=G(1)
      U(1)=Z(1)/W(1)
      DO J=2,JINC
        JM1=J-1
        SV(JM1)=F(JM1)/W(JM1)
        W(J)=G(J)-H(J)*SV(JM1)
        U(J)=(Z(J)-H(J)*U(JM1))/W(J)
      END DO
      T(JINC)=U(JINC)
      KK=JINC-1
      DO J=1,KK
        KMJ=JINC-J
        IF (IFLAG(KMJ).NE.1) THEN
          T(KMJ)=U(KMJ)-SV(KMJ)*T(KMJ+1)
          IF (JFLAG(KMJ).NE.1) THEN
            IF (T(KMJ).GE.BOIL) THEN
              T(KMJ) = BOIL
              IF (KMJ.NE.1) THEN
                Q(KMJ) = BK(KMJ,1)*(T(KMJ)-T(KMJ+1))/H1
              ELSEIF (KMJ.EQ.1) THEN
                Q(KMJ) = QT
              END IF
              XTIME(KMJ) = 539.*H1/Q(KMJ)*WATER(KMJ,1)
              ZTIME(KMJ) = XTIME(KMJ)+TIME
              IFLAG(KMJ) = 1
            END IF
          END IF
          ELSEIF (IFLAG(KMJ).EQ.1) THEN
            IF (TIME.GE.ZTIME(KMJ)) THEN
              WATER(KMJ,1) = PCWATR
              CP(KMJ,1)=(CPCON(1)*WATER(KMJ,1)+CPCON(2))/(ROCON(1)*
+ WATER(KMJ,1)+ROCON(2))
              BK(KMJ,1) = (THCON(1)*WATER(KMJ,1)+THCON(2))/(ROCON(1)
+ *WATER(KMJ,1)+ROCON(2))
              IFLAG(KMJ) = 0
              XTIME(KMJ) = 0.
              JFLAG(KMJ) = 1
            END IF
          ENDIF
        END DO
      C*****Interpolate extra temperatures between the surface and second node
      IF (NXTRA.NE.0) THEN
        IF (T(2).EQ.T(1)) THEN
      C*****For constant temperature
        DO I=1,NXTRA
          XTMP(I) = T(2)

```

```

      END DO
      ELSEIF (T(2).EQ.T(3)) THEN
C*****Linear interpolation
      DO I=1,NXTRA
        P = XTRA(I)/D2          !D(1) = 0.
        XTMP(I) = (1.-P)*T(1)+P*T(2)
      END DO
      ELSE
C*****3-point Lagrange interpolation for equally spaced abscissae
      DO I=1,NXTRA
        P = (XTRA(I)-D2)/D2          !D(1) = 0. (SURFACE)
        XTMP(I) = .5*P*(P-1.)*T(1)+(1.-P**2)*T(2)+.5*P*(P+1.)
+ *T(3)
      END DO
      END IF
      END IF
      IF (ABS(ETIME-TIME) .LE. 0.5*AK) THEN
        DO I=1,JINC
          IF (IFLAG(I).NE.0) THEN
            WATER(I,1) = (ZTIME(I)-TIME)/XTIME(I)*(WATER(I,1)-
+ PCWATR)+PCWATR
            CP(I,1) = (CPCON(1)*WATER(I,1)+CPCON(2))/(ROCON(1)*
+ WATER(I,1)+ROCON(2))
            BK(I,1) = (THCON(1)*WATER(I,1)+THCON(2))/(ROCON(1)*
+ WATER(I,1)+ROCON(2))
          END IF
        END DO
        DO I=1,JINC
          XTIME(I) = 0.
          IFLAG(I) = 0
          JFLAG(I) =1
        END DO
      ENDIF
      IF (T(1).GT.TMPMAX) TMPMAX=T(1)
      ITFLG = -1 !ITFLG SET TO 0 IF ANY TEMPERATURE .GE. 44 DEGREES
      DO J=1,JINC
        IF (T(J).LT.44.) THEN
          DW(J) = 0.
        ELSE
          ITFLG = 0
          IF(T(J).LT.50.) THEN
            PL1 = PPL1
            PLN1 = PPLN1
            DE1 = DDE1
            APL1 = APPL1
            APLN1 = APPLN1
            ADE1 = ADDE1
            DWLN=PL1+PLN1-DE1/(T(J)+273.)
            IF(DWLN.GE.87.0) DWLN = 87.0
            DW(J) = EXP(DWLN)
          ELSE
            PL1=PL2

```

```

      PLN1=PLN2
      DE1=DE2
      APL1 = APL2
      APLN1 = APLN2
      ADE1 = ADE2
      IF(J.LE.1) THEN
        DWLN = APL1 + APLN1-ADE1/(T(1)+273.)
        IF(DWLN.GE.87.0) DWLN = 87.0
        DW(1) = EXP(DWLN)
      ELSE
        DWLN=PL1+PLN1-DE1/(T(J)+273.)
        IF(DWLN.GE.87.0) DWLN = 87.0
        DW(J) = EXP(DWLN)
      END IF
    END IF
  END DO
  IF (JJJJ.LT.2) THEN
    DO I=1,JINC
      SUM(I) = .5*DW(I)
    END DO
  ELSE
    DO I=1,JINC
      IF (SUM(I).LT.(1.0E38)) SUM(I)=SUM(I)+DW(I)
    END DO
  END IF
  IF (NXTRA.NE.0) THEN
    DO J=1,NXTRA
      IF (XTMP(J).LT.44.) THEN
        XDW(J) = 0.
      ELSE
        IF (XTMP(J).LT.50.) THEN
          APL1 = APPL1
          APLN1 = APPLN1
          ADE1 = ADDE1
        ELSE
          APL1 = APL2
          APLN1 = APLN2
          ADE1 = ADE2
        END IF
        IF (TP.EQ.999..AND.XTMP(4).GE.45.)
+ TP=TIME
          DWLN = APL1+APLN1-ADE1/(XTMP(J)+273.)
          IF(DWLN.GE.87.0) DWLN=87.0
          XDW(J) = EXP(DWLN)
        END IF
      END DO
    IF (JJJJ.LT.2) THEN
      DO J=1,NXTRA
        XSUM(J) = 0.5*XDW(J)
      END DO
    ELSE

```

```

DO J=1,NXTRA
  IF (XSUM(J).LT.1.OE38) XSUM(J)=XSUM(J)+XDW(J)
END DO
END IF
END IF
EMTIME = AINT(1000.*(TIME+.00001))/100.
IF (TIME.LT.10..AND.AMOD(EMTIME,1.).EQ.0..OR.TIME.GE.10.
+ .AND.AMOD(EMTIME,10.).EQ.0.) THEN
  WRITE(4,420)TIME,T(1),T(2),T(3),T(4),T(5),T(6),T(7),
+ T( 8),T(9),T(10),T(11),T(12)
  PTS=PTS+1
ENDIF
IF (ITFLG.NE.0.AND.TIME.GE.ETIME.OR.JJJJ.EQ.M*100.OR.JJJJ
+ .EQ.1) CALL SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
END DO
REWIND(4)
CLOSE(4)
DO I=1,JINC
  W(I) = (SUM(I)-.5*DW(I))*AK
END DO
IF (NXTRA.NE.0) THEN
  DO J=1,NXTRA
    XW(J) = (XSUM(J)-.5*XDW(J))*AK
  END DO
END IF
C*****Select W(J) and D(J) near W(J) =1
470   NN = 3
      J=1
      DOWHILE(J.LE.JINC)
        JLT1 = J
        IF(W(J).GT.1.) THEN
          IF(J.EQ.JINC) THEN
            NN=2
            WRITE(3,440)(W(K),K=JLT1-1,JLT1+1)
            WRITE(7, 440)(W(K),K=JLT1-1,JLT1+1)
440   FORMAT(/(1X,'W=',E20.5))
            WRITE(3,450)(D(K),K=JLT1-1,JLT1+1)
            WRITE(7,450)(D(K),K=JLT1-1,JLT1+1)
450   FORMAT(/(1X,'D=',E20.5))
          END IF
          J=J+1
        ELSEIF(W(J).EQ.1.) THEN
          MN=1
          J=JINC+1
        ELSEIF(W(J).LT.1.) THEN
          IF (J.EQ.1) JLT1=2
          IF (J.EQ.JINC) JLT1=JINC-1
          WRITE(3,440)(W(K),K=JLT1-1,JLT1+1)
          WRITE(7,440)(W(K),K=JLT1-1,JLT1+1)
          WRITE(3,450)(D(K),K=JLT1-1,JLT1+1)
          WRITE(7,450)(D(K),K=JLT1-1,JLT1+1)
          IF (NXTRA0.NE.0.AND.JLT1.LE.2) THEN

```

```

        WRITE(*,460)
460    FORMAT(/,9X,'W=1 LIES ABOVE NODE 2. INTERCOLLATING VALUES OF D'/
+ ,9X,'AND W COMPUTED FROM INTERPOLATED VALUES OF D AND',/,9X,
+ 'TEMPERATURE. ',/)
        WRITE(3,460)
        WRITE(7,460)
        WRITE(1)D(1)
        WRITE(2)W(1)
        DO J=1,NXTRA
            WRITE(1)XTRALG(J)
            WRITE(2)XW(J)
        END DO
        DO J=2,JINC
            WRITE(1)D(J)
            WRITE(2)W(J)
        END DO
        REWIND 1
        REWIND 2
        DO J=1,JINC
            READ(1)D(J)
            READ(2)W(J)
        END DO
        REWIND 1
        REWIND 2
        NXTRAO = 0
        GO TO 470
    END IF
    J=JINC+1
END IF
END DO
IF(MN.EQ.0) THEN
    NXTRAO = NXTRA
    IF (W(JLT1+1).EQ.0..AND.NN.EQ.3) NN=2
    IF(W(JLT1-1).LT.1.0)THEN
        TD=0.0
        IERR=0
    ELSE
        CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
C*****If Lagrangian interpolation didn't work, use linear interpolation
        IF(NN.EQ.3) THEN
            IF(W(JLT1-1).GE.1.0.AND.W(JLT1).LE.1.0.AND.(D(JLT1-1).
+             GT.TD.OR.D(JLT1).LT.TD)) THEN
                NN=2
                CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
            ELSEIF (W(JLT1).GE.1.0.AND.W(JLT1+1).LE.1.0.AND.
+             (D(JLT1).GT.TD.OR.D(JLT1+1).LT.TD)) THEN
                JLT1=JLT1+1
                NN=2
                CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
            ENDIF
        ENDIF
    ENDIF
ENDIF
ENDIF

```

```

        IF (IERR.NE.0) THEN
            WRITE(*,480)
            WRITE(3,480)
            WRITE(7,480)
480    FORMAT(9X,'ERROR IN SUBROUTINE "DEPTH". EXITING.'/)
            CALL ANOTHER(AGAIN)
        ENDIF
        IF (NN.EQ.2.AND.JLT1.EQ.JINC) THEN
            WRITE(3,490)MAXDIM
            WRITE(7,490)MAXDIM
490    FORMAT(/1X,'THE MODEL BLEW UP: DAMAGE > 1 AT NODE ',I2/)
            CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
        ELSE
            CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
        ENDIF
        ELSE
            TD=EXP(D(J))
            CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
        END IF
        CALL HARVARD(PROFILE,TFILE,SUMFILE,PTS)
    END IF
ELSEIF(PROCED.EQ.1) THEN
    IF(AGAIN.EQ.0) THEN
        CALL SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,
+    ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
+    BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
    ENDIF
    ENDIF
END DO
CLOSE(1)
CLOSE(2)
CLOSE(3)
CLOSE(4)
CLOSE(7)
CALL COLORS
DUMMY2=SETVIDEOMODE( $DEFAULTMODE )
STOP
END

SUBROUTINE COLORS
    INCLUDE 'FGRAPH.FD'
    INTEGER*2 LOOP,LOOP1,DUMMY2
    REAL RND1,RND2
    DUMMY2=SETVIDEOMODE( $MRES256COLOR )
    DO LOOP1=1,10
        WRITE(*,10)
10    FORMAT(///,10X,'BURNSIM',///,15X,'BURNSIM',///,20X,'BURNSIM')
        DUMMY2=SETCOLOR(MOD( getcolor()+1, 16)) ! Set next color

        DO loop=1,3200
C*****Set a random pixel, normalized to be on the screen
            CALL RANDOM( RND1 )

```



```

        CALL RANDOM( RND2 )
        DUMMY2=SETPIXEL( INT2( RND1*320 ),INT2( RND2*200 ) )
    END DO
END DO
DUMMY2=SETVIDEOMODE( $MAXRESMODE )
END

SUBROUTINE WELCOME(PROFILE)
    CHARACTER PROFILE*8
    CALL CLEARSCREEN( $GCLEARSCREEN )
    WRITE(*,10)
10    FORMAT(//,9X,'WELCOME TO BURNSIM. TO BEGIN RUNNING THE PROGRAM,',
+ ' BURNSIM',/,9X,'FIRST NEEDS TO KNOW THE NAME OF THE FILE THAT',
+ ' YOU WANT TO',/,9X,'STORE THE OUTPUT DATA IN. THIS FILE WILL',
+ ' CONTAIN ALL OF THE',/,9X,'INPUT PARAMETERS AS WELL AS THE',
+ ' OUTPUT FOR EACH ITERATION THE',/,9X,'MODEL PERFORMS. THIS',
+ ' FILE CAN BE CALLED ANYTHING UP TO EIGHT',/,9X,'CHARACTERS',
+ ' LONG.',/,15X,'PLEASE ENTER A NAME FOR THE OUTPUT FILE: '$)
    READ(*,20)PROFILE
20    FORMAT(A8)
C*****Set up parameters for this run
    CALL CLEARSCREEN( $GCLEARSCREEN )
    WRITE(*,30)
30    FORMAT(///,9X,'NEXT BURNSIM WILL SHOW YOU THE PRESENT INPUT',
+ ' PARAMETERS.',/,9X,'UNDER THE LIST OF PARAMETERS YOU WILL SEE A'
+ ' QUESTION ASKING',/,9X,'IF YOU WISH TO CONTINUE. IF YOU WANT',
+ ' TO EXIT THE PROGRAM AT ',/,9X,'THAT POINT, TYPE N. OTHERWISE',
+ ' TYPE Y.',///,9X,'TO CONTINUE ON TO THE LIST OF INPUT',
+ ' PARAMETERS TYPE A <CR>.')
    READ(*,*)
    END

SUBROUTINE READDATA(TEMPIO,DENS,QO,BL,AK,BOIL,ABSORB,JINC,
+ TEMPB,ITIME,ETIME,PCWATR,BLOOD,CP,BK,PL2,PLN2,PL1,PLN1,DE2,
+ DE1,APL1,APLN1,APL2,APLN2,ADE1,ADE2,WATER)
    REAL ITIME
    DIMENSION CP(12,2),BK(12,2),WATER(12,2)
    OPEN(UNIT=1,FILE='REN12.DAT',FORM='FORMATTED',STATUS='OLD')
    READ(1,10)TEMPIO,DENS,QO,BL,AK,BOIL,ABSORB
10    FORMAT(7F10.5)
    READ(1,20)JINC,TEMPB,ITIME,ETIME,PCWATR,BLOOD
20    FORMAT(1I10,5F10.5)
    READ(1,30)(CP(J,2),J=1,JINC)
30    FORMAT(6F10.5)
    READ(1,30)(BK(J,2),J=1,JINC)
    READ(1,30)PL2,PLN2,PL1,PLN1,DE2,DE1
    READ(1,30)APL1,APLN1,APL2,APLN2,ADE1,ADE2
    READ(1,30,END=40)(WATER(I,2),I=1,JINC)
40    CLOSE(1)
    CALL CLEARSCREEN( $GCLEARSCREEN )
    END

```

```

SUBROUTINE SHOWVALUE(TEMP10,DENS,FLUX,BL,AK,JINC,TEMPB,
+ ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,
+ NXTRA,BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
  REAL ITIME
  DIMENSION FLUX(600),XTRA(8)
  CALL CLEARSCREEN( $GCLEARSCREEN )
  IF(K.NE.1) THEN
    WRITE (*,10)
10  FORMAT(///,30X,'SKIN DIFFUSION DATA'//,30X,'INPUT PARAMETER LIST')
    WRITE(*,20)TEMP10,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
20  FORMAT(/,4X,'TEMP10 = ',F10.5,6X,'DENS = ',F10.5,7X,'Q1 = ',
+ F10.5,/,4X,'BL = ',F10.5,10X,'AK = ',F10.5,9X,'JINC = ',I2,/,4X,
+ 'TEMPB = ',F10.5,7X,'ABSORB = ',F10.5,5X,'BOIL = ',F10.5,/)
    WRITE (*,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
30  FORMAT(4X,'PL1 = ',F10.5,9X,'PLN1 = ',F10.5,7X,'DE1 = ',F10.1,/,
+ 4X,'PL2 = ',F10.5,9X,'PLN2 = ',F10.5,7X,'DE2 = ',F10.1,/,4X,
+ 'ETIME = ',F10.5,7X,'ITIME = ',F10.5,6X,'NXTRA = ',I2,/,4X,
+ 'BLOOD = ',F10.5,/)
    WRITE(*,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
40  FORMAT(4X,'APL1 = ',F10.5,8X,'APLN1 = ',F10.5,6X,'ADE1 = ',F10.1,
+ /,4X,'APL2 = ',F10.5,8X,'APLN2 = ',F10.5,6X,'ADE2 = ',F10.1,/)
    IF (NXTRA.GT.0) WRITE(*,50) (XTRA(I),I=1,NXTRA)
50  FORMAT(5X,'THE EXTRA NODES ARE: ',8F6.1)
    ELSE
      WRITE(3,10)
      WRITE(7,10)
      WRITE(3,20)TEMP10,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
      WRITE(7,20)TEMP10,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
      WRITE (3,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
      WRITE (7,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
      WRITE(3,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
      WRITE(7,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
      IF (NXTRA.GT.0) WRITE(3,50) (XTRA(I),I=1,NXTRA)
      IF (NXTRA.GT.0) WRITE(7,50) (XTRA(I),I=1,NXTRA)
      K=0
    ENDIF
  END

```

```

SUBROUTINE PROCEED(RESP,PROCED,AGAIN)
  CHARACTER RESP*1
  INTEGER PROCED,AGAIN
  WRITE(*,10)
10  FORMAT(//,15X,'DO YOU WISH TO CONTINUE? TYPE Y OR N '$)
  READ(*,20)RESP
20  FORMAT(A1)
  IF (RESP.EQ.'Y'.OR.RESP.EQ.'Y') THEN
    PROCED=0
  ELSE
    PROCED=1
    CALL ANOTHER(AGAIN)
  ENDIF
END

```

```

SUBROUTINE ANOTHER(AGAIN)
  CHARACTER RESP*1
  INTEGER AGAIN
  WRITE(*,10)
10  FORMAT(//,15X,'DO YOU WANT TO DO ANOTHER RUN?  TYPE Y OR N '$)
  READ(*,20)RESP
20  FORMAT(A1)
  IF(Resp.EQ.'Y'.OR.Resp.EQ.'y') THEN
    AGAIN=0
  ELSE
    AGAIN=1
  END IF
  END

SUBROUTINE DESCRIPT(DSCRPT,SUMFILE,TFILE)
  CHARACTER SUMFILE*8,TFILE*8
  DIMENSION DSCRPT(20)
  WRITE(*,10)
10  FORMAT(///,9X,'ENTER THE MODEL NAME OR DESCRIPTION (UP TO 80',
+  /,9X,'CHARACTERS).  THIS INFORMATION WILL BE USED',/,9X,
+  'AS A TITLE ON THE SUMMARY PAGE. '$)
  READ(*,20)DSCRPT
20  FORMAT(20A4)
  WRITE(3,30)DSCRPT
30  FORMAT(//,10X,'MODEL NAME OR DESCRIPTION: ',20A4)
  CALL CLEARSCREEN( $GCLEARSCREEN )
  WRITE(*,40)
40  FORMAT(///,9X,'NOW ENTER THE SUMMARY FILENAME (UP TO 8',
+  /,9X,'CHARACTERS).  THIS FILE WILL CONTAIN A',/,9X,'SUMMARY'
+  ' OF THE SIMULATION. '$)
  READ(*,50)SUMFILE
50  FORMAT(A8)
  OPEN(UNIT=7,FILE=SUMFILE,FORM='FORMATTED',STATUS='UNKNOWN')
  WRITE(7,30)DSCRPT
  CALL CLEARSCREEN( $GCLEARSCREEN )
  WRITE(*,60)
60  FORMAT(///,9X,'NOW ENTER THE TEMPERATURE FILE (UP TO 8',
+  ' CHARACTERS).',/,9X,'THIS FILE WILL CONTAIN A LIST OF THE',
+  ' TEMPERATURES',/,9X,'AT THE VARIOUS NODES DURING THE SIMULATION'
+  '. '$)
  READ(*,70)TFILE
70  FORMAT(A8)
  OPEN(UNIT=4,FILE=TFILE,FORM='FORMATTED',STATUS='UNKNOWN')
  END

SUBROUTINE SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
  DIMENSION T(12),XTIME(12),CP(12,2),BK(12,2),XTMP(8)
  WRITE(3,10)TIME
  WRITE(*,10)TIME,(T(I),XTIME(I),I=1,JINC)
10  FORMAT(/,45X,5HTIME=F10.6:,T4,'T= ',6X,'XTIME='/(',2G12.4))
  WRITE(*,20)BLUD
20  FORMAT(1X,'BLUD =',F6.5)

```

```

        WRITE(3,30)(XTIME(I),I=1,JINC)
30      FORMAT(2X,'XTIME=',F10.5)
        WRITE(3,40)T(1),CP(1,1),BK(1,1)
40      FORMAT(2X,'T=',G16.5:,2X,'CP=',G16.5,2X,'BK=',G16.5)
        IF (NXTRA.NE.0) THEN
            DO J=1,NXTRA
                WRITE(3,40)XTMP(J)
            END DO
        END IF
        WRITE(3,40)(T(J),CP(J,1),BK(J,1),J=2,JINC)
        M=M+1
        EM = M
    END

```

```

    SUBROUTINE DEPTH(X,Y,N,TD,IERR)
C*****Inverse interpolation on two or three points to determine
C      threshold depth (predicted burn depth) using either Y or LOG(Y)
        DIMENSION X(1),Y(1),Z(3)
        IERR = 0
        IF (N.LT.2) IERR=-1
        IF(IERR.NE.-1) THEN
            DO 100 I=1,N
                Z(I) = Y(I)
                Z0 = 1.
                IF (Z(1).NE.0..AND.Z(2).NE.0.) THEN          !USE LOGARITHMS?
                    IF (N.EQ.3.AND.Z(3).EQ.0.) N=2
                    Z0 = 0.          !USE LOGARITHMS
                DO 120 I=1,N
                    Z(I) = ALOG(Z(I))
                END IF
            140      H0 = Z(2)-Z(1)
                    IF (H0.EQ.0.) IERR=-1
                    IF (N.NE.2.AND.IERR.NE.-1) THEN
                        H1 = Z(3)-Z(2)
                        IF (H1.EQ.0.) IERR=-1
                        IF(IERR.NE.-1) H2 = Z(3)-Z(1)
                        IF (H2.EQ.0.) IERR=-1
                        IF(IERR.NE.-1) DZ3 = Z0-Z(3)
                    END IF
                    IF(IERR.NE.-1) THEN
            160      DZ2 = Z0-Z(2)
                        DZ1 = Z0-Z(1)
                        IF (N.NE.2) THEN
                            TD = DZ1*DZ2*X(3)/(H1*H2)-DZ1*X(2)*DZ3/(H0*H1)+X(1)*DZ2*DZ3
                            + /(H0*H2)
                            ELSEIF(N.EQ.2) THEN
            180      TD = (DZ1*X(2)-X(1)*DZ2)/H0
                        END IF
            200      TD = EXP(TD)
                    END IF
                END IF
            END

```

```

SUBROUTINE SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
  DIMENSION W(12),D(12)
  WRITE(3,10)(W(I),I=1,JINC)
10  FORMAT(/(1X,'W=',E20.5))
  WRITE(7,20)(W(I),EXP(D(I)),I=1,JINC)
20  FORMAT(/(1X,'W=',E20.5,5X,'AT DEPTH (IN MICRONS)=',G20.6))
  WRITE(3,30)TMPMAX
  WRITE(7,30)TMPMAX
  WRITE(*,30)TMPMAX
30  FORMAT(/,1X,'MAXIMUM TEMPERATURE = ',F8.3)
  WRITE(*,40)TD
  WRITE(3,40)TD
  WRITE(7,40)TD
40  FORMAT(/,1X,'THRESHOLD DEPTH = ',G20.4)
  WRITE(3,50)TIME
  WRITE(7,50)TIME
  WRITE(*,50)TIME
50  FORMAT(/,1X,'FINAL TIME = ',F7.2)
  IF(TP.NE.999.) THEN
    WRITE(3,60)TP
    WRITE(7,60)TP
    WRITE(*,60)TP
60  FORMAT(/,1X,'TIME TO PAIN IS ',F7.2,' SECONDS.')
    END IF
  END

SUBROUTINE HARVARD(PROFILE,TFILE,SUMFILE,PTS)
  CHARACTER PROFILE*8,SUMFILE*8,TFILE*8,HGPLOT*1,HG*12
  INTEGER PTS
  WRITE(*,10)
10  FORMAT(///,9X,'TYPE A <CR> TO CONTINUE.')
  READ(*,*)
  CALL CLEARSCREEN( $GCLEARSCREEN )
  WRITE(*,20)
20  FORMAT(///,9X,'DO YOU WANT TO PLOT THE TEMPERATURES VS. TIME',/,
+ 9X,'TIME IN HARVARD GRAPHICS? TYPE Y/N '$)
  READ(*,30) HGPLOT
30  FORMAT(A1)
  IF(HGPLOT.EQ. 'Y' .OR. HGPLOT.EQ. 'y') THEN
    CALL PLOTHG(PTS,TFILE,HG)
  ENDIF
  CALL CLEARSCREEN( $GCLEARSCREEN )
  WRITE(*,40)PROFILE,TFILE
40  FORMAT(///,9X,'THE MODEL OUTPUT IS FOUND IN FILE: ',A10,/,9X,
+ 'USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.',
+ //,9X,'THE TEMPERATURES AT EACH NODE ARE IN FILE: ',A10,/,9X,
+ 'USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.')
  IF(HGPLOT.EQ. 'Y' .OR. HGPLOT.EQ. 'y') THEN
    WRITE(*,50)HG
50  FORMAT(///,9X,'THE TEMPERATURES FOR THE HARVARD GRAPHICS PLOT',
+ ' ARE IN FILE: ',/,9X,A12,'. USE "PRINT" OR "TYPE" AFTER YOU',
+ ' EXIT THE PROGRAM',/,9X,'TO SEE IT.')

```

```

        ENDIF
        WRITE(*,60)SUMFILE
60      FORMAT(/,9X,'THE SUMMARY PRINTOUT IS IN FILE: ',A10,/,9X,'USE',
+ ' "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.',///,
+ 12X,'TYPE A <CR> TO CONTINUE.')
        READ(*,*)
        CALL CLEARSCREEN( $GCLEARSCREEN )
        END

        SUBROUTINE PLOTHG(PTS,TPFILE,HG)
        REAL TIME(800),T1(800),T2(800),T3(800),T4(800),T5(800),
+ T6(800),T7(800),T8(800),T9(800),T10(800),T11(800),T12(800)
        INTEGER PTS
        CHARACTER HG*12,TPFILE*8
        OPEN(UNIT=4,FILE=TPFILE,FORM='FORMATTED',STATUS='UNKNOWN')
        DO I=1,PTS
            READ(4,40) TIME(I),T1(I),T2(I),T3(I),T4(I),T5(I)
+ ,T6(I),T7(I),T8(I),T9(I),T10(I),T11(I),T12(I)
40      FORMAT(13(F9.5,2X))
            END DO
            WRITE(*,10)TPFILE
            CLOSE(4)
10      FORMAT(/,9X,'THE TEMPERATURE DATA IS STORED IN FILE: ',A8)
            WRITE(*,20)
20      FORMAT(/,9X,'ENTER THE FILE TO STORE HARVARD GRAPHICS ',/,
+ 9X,'TEMPERATURES USING UP TO 12 CHARACTERS',/,9X,'INCLUDING'
+ ' THE ENDING .DAT ', $)
            READ(*,30) HG
30      FORMAT(A12)
            IF(PTS.LE.60) THEN
                OPEN(UNIT=5,FILE=HG,FORM='FORMATTED',STATUS='UNKNOWN')
                DO J=1,PTS
                    WRITE(5,60) TIME(J),T1(J),T2(J),T3(J),T4(J),T5(J),
+ T6(J),T7(J),T8(J),T9(J),T10(J),T11(J),T12(J)
60      FORMAT(13(F9.5,2X))
                END DO
                CLOSE(5)
            ELSE
                INTERVAL=INT(PTS/60)
                OPEN(UNIT=5,FILE=HG,FORM='FORMATTED',STATUS='UNKNOWN')
                DO J=1,PTS,INTERVAL
                    WRITE(5,80) TIME(J),T1(J),T2(J),T3(J),T4(J),T5(J),
+ T6(J),T7(J),T8(J),T9(J),T10(J),T11(J),T12(J)
80      FORMAT(13(F9.5,2X))
                END DO
                CLOSE(5)
            END IF
        END

```

APPENDIX C

REN12.DAT

This next file contains the initial values of the variables and constants required by BURNSIM. The file is REN12.DAT.

```
32.5,1.,3.54,0.22,0.01,100.15,0.613
12,4.5,80.,3.02,0.137,0.001
.5139,.8513,.8678,.8681,.8561,.8349,.8086
.7802,.7537,.7326,.7209,.7209
.00059604,.0012236,.0012541,.0012547,.0012322,.0011931,.0011439
.0010912,.0010419,.0010028,.0009810,.0008
2.24,239.47,1.46,147.37,80000.,50000.
.78,285.52,.60,117.43,93534.9,39109.8
.137,.72596,.75574,.75638,.73439,.69632,.64869
.598,.55081,.51364,.49298,.3
```

See the users manual for definitions of these abbreviations (eg. TEMPIO).

ROW 1
 TEMPIO = 32.5
 DENS = 1.
 QO = 3.54
 BL = 0.22
 AK = 0.01
 BOIL = 100.15
 ASORB = 0.613

ROW 2
 JINC = 12
 TEMPB = 4.5
 ITIME = 80.
 ETIME = 3.02
 PCWATER = 0.137
 BLOOD = 0.001

ROW 3
 Cp(1) = .5139
 Cp(2) = .8513
 Cp(3) = .8678
 Cp(4) = .8561
 Cp(5) = .8561
 Cp(6) = .8349
 Cp(7) = .8086

ROW 4
 Cp(8) = .7802
 Cp(9) = .7537
 Cp(10) = .7326
 Cp(11) = .7209
 Cp(12) = .7209

ROW 5
 BK(1) = .00059604
 BK(2) = .0012236
 BK(3) = .0012541
 BK(4) = .0012547
 BK(5) = .0012322
 BK(6) = .0011931
 BK(7) = .0011439

ROW 6
 BK(8) = .0010912
 BK(9) = .0010419
 BK(10) = .0010028
 BK(11) = .0009810
 BK(12) = .0008

ROW 7
 PL2 = 2.24
 PLN2 = 239.47
 PL1 = 1.46
 PLN1 = 147.37
 DE2 = 80000.
 DE1 = 50000.

ROW 8
 APL1 = .78
 APLN1 = 285.52
 APL2 = .60
 APLN2 = 117.43
 ADE1 = 93534.9
 ADE2 = 39109.8

ROW 9
 WATER(1) = .137
 WATER(2) = .72596
 WATER(3) = .75574
 WATER(4) = .75638
 WATER(5) = .73439
 WATER(6) = .69632
 WATER(7) = .64869

ROW 10
 WATER(8) = .598
 WATER(9) = .55081
 WATER(10) = .51364
 WATER(11) = .49298
 WATER(12) = .3

Initial distribution

Commander, U.S. Army Natick Research,
Development and Engineering Center
ATTN: SATNC-MIL (Documents
Librarian)
Natick, MA 01760-5040

U.S. Army Communications-Electronics
Command
ATTN: AMSEL-RD-ESA-D
Fort Monmouth, NJ 07703

Commander/Director
U.S. Army Combat Surveillance
and Target Acquisition Lab
ATTN: DELCS-D
Fort Monmouth, NJ 07703-5304

Commander
10th Medical Laboratory
ATTN: Audiologist
APO New York 09180

Naval Air Development Center
Technical Information Division
Technical Support Detachment
Warminster, PA 18974

Commanding Officer, Naval Medical
Research and Development Command
National Naval Medical Center
Bethesda, MD 20814-5044

Deputy Director, Defense Research
and Engineering
ATTN: Military Assistant
for Medical and Life Sciences
Washington, DC 20301-3080

Commander, U.S. Army Research
Institute of Environmental Medicine
Natick, MA 01760

Library
Naval Submarine Medical Research Lab
Box 900, Naval Sub Base
Groton, CT 06349-5900

Director, U.S. Army Human
Engineering Laboratory
ATTN: Technical Library
Aberdeen Proving Ground, MD 21005

Commander
Man-Machine Integration System
Code 602
Naval Air Development Center
Warminster, PA 18974

Commander
Naval Air Development Center
ATTN: Code 602-B (Mr. Brindle)
Warminster, PA 18974

Commanding Officer
Armstrong Laboratory
Wright-Patterson
Air Force Base, OH 45433-6573

Director
Army Audiology and Speech Center
Walter Reed Army Medical Center
Washington, DC 20307-5001

Commander, U.S. Army Institute
of Dental Research
ATTN: Jean A. Setterstrom, Ph. D.
Walter Reed Army Medical Center
Washington, DC 20307-5300

Commander, U.S. Army Test
and Evaluation Command
ATTN: AMSTE-AD-H
Aberdeen Proving Ground, MD 21005

Naval Air Systems Command
Technical Air Library 950D
Room 278, Jefferson Plaza II
Department of the Navy
Washington, DC 20361

Director
U.S. Army Ballistic
Research Laboratory
ATTN: DRXBR-OD-ST Tech Reports
Aberdeen Proving Ground, MD 21005

Commander
U.S. Army Medical Research
Institute of Chemical Defense
ATTN: SGRD-UV-AO
Aberdeen Proving Ground,
MD 21010-5425

Commander, U.S. Army Medical
Research and Development Command
ATTN: SGRD-RMS (Ms. Madigan)
Fort Detrick, Frederick, MD 21702-5012

Director
Walter Reed Army Institute of Research
Washington, DC 20307-5100

HQ DA (DASG-PSP-O)
5109 Leesburg Pike
Falls Church, VA 22041-3258

Harry Diamond Laboratories
ATTN: Technical Information Branch
2800 Powder Mill Road
Adelphi, MD 20783-1197

U.S. Army Materiel Systems
Analysis Agency
ATTN: AMXSU-PA (Reports Processing)
Aberdeen Proving Ground
MD 21005-5071

U.S. Army Ordnance Center
and School Library
Simpson Hall, Building 3071
Aberdeen Proving Ground, MD 21005

U.S. Army Environmental
Hygiene Agency
Building E2100
Aberdeen Proving Ground, MD 21010

Technical Library Chemical Research
and Development Center
Aberdeen Proving Ground, MD
21010-5423

Commander
U.S. Army Medical Research
Institute of Infectious Disease
SGRD-UIZ-C
Fort Detrick, Frederick, MD 21702

Director, Biological
Sciences Division
Office of Naval Research
600 North Quincy Street
Arlington, VA 22217

Commander
U.S. Army Materiel Command
ATTN: AMCDE-XS
5001 Eisenhower Avenue
Alexandria, VA 22333

Commandant
U.S. Army Aviation
Logistics School ATTN: ATSQ-TDN
Fort Eustis, VA 23604

Headquarters (ATMD)
U.S. Army Training
and Doctrine Command
ATTN: ATBO-M
Fort Monroe, VA 23651

Structures Laboratory Library
USARTL-AVSCOM
NASA Langley Research Center
Mail Stop 266
Hampton, VA 23665

Naval Aerospace Medical
Institute Library
Building 1953, Code 03L
Pensacola, FL 32508-5600

Command Surgeon
HQ USCENTCOM (CCSG)
U.S. Central Command
MacDill Air Force Base FL 33608

Air University Library
(AUL/LSE)
Maxwell Air Force Base, AL 36112

U.S. Air Force Institute
of Technology (AFIT/LDEE)
Building 640, Area B
Wright-Patterson
Air Force Base, OH 45433

Henry L. Taylor
Director, Institute of Aviation
University of Illinois-Willard Airport
Savoy, IL 61874

Chief, National Guard Bureau
ATTN: NGB-ARS (COL Urbauer)
Room 410, Park Center 4
4501 Ford Avenue
Alexandria, VA 22302-1451

Commander
U.S. Army Aviation Systems Command
ATTN: SGRD-UAX-AL (LTC Gillette)
4300 Goodfellow Blvd., Building 105
St. Louis, MO 63120

U.S. Army Aviation Systems Command
Library and Information Center Branch
ATTN: AMSAV-DIL
4300 Goodfellow Boulevard
St. Louis, MO 63120

Federal Aviation Administration
Civil Aeromedical Institute
Library AAM-400A
P.O. Box 25082
Oklahoma City, OK 73125

Commander
U.S. Army Academy
of Health Sciences
ATTN: Library
Fort Sam Houston, TX 78234

Commander
U.S. Army Institute of Surgical Research
ATTN: SGRD-USM (Jan Duke)
Fort Sam Houston, TX 78234-6200

AAMRL/HEX
Wright-Patterson
Air Force Base, OH 45433

John A. Dellinger,
Southwest Research Institute
P. O. Box 28510
San Antonio, TX 78284

Product Manager
Aviation Life Support Equipment
ATTN: AMCPM-ALSE
4300 Goodfellow Boulevard
St. Louis, MO 63120-1798

Commander
U.S. Army Aviation
Systems Command
ATTN: AMSAV-ED
4300 Goodfellow Boulevard
St. Louis, MO 63120

Commanding Officer
Naval Biodynamics Laboratory
P.O. Box 24907
New Orleans, LA 70189-0407

Assistant Commandant
U.S. Army Field Artillery School
ATTN: Morris Swott Technical Library
Fort Sill, OK 73503-0312

Commander
U.S. Army Health Services Command
ATTN: HSOP-SO
Fort Sam Houston, TX 78234-6000

U.S. Army Dugway Proving Ground
Technical Library, Building 5330
Dugway, UT 84022

U.S. Army Yuma Proving Ground
Technical Library
Yuma, AZ 85364

AFFTC Technical Library
6510 TW/TSTL
Edwards Air Force Base,
CA 93523-5000

Commander
Code 3431
Naval Weapons Center
China Lake, CA 93555

Aeromechanics Laboratory
U.S. Army Research and Technical Labs
Ames Research Center, M/S 215-1
Moffett Field, CA 94035

Sixth U.S. Army
ATTN: SMA
Presidio of San Francisco, CA 94129

Commander
U.S. Army Aeromedical Center
Fort Rucker, AL 36362

U.S. Air Force School
of Aerospace Medicine
Strughold Aeromedical Library Technical
Reports Section (TSKD)
Brooks Air Force Base, TX 78235-5301

Dr. Diane Damos
Department of Human Factors
ISSM, USC
Los Angeles, CA 90089-0021

U.S. Army White Sands
Missile Range
ATTN: STEWS-IM-ST
White Sands Missile Range, NM 88002

U.S. Army Aviation Engineering
Flight Activity
ATTN: SAVTE-M (Tech Lib) Stop 217
Edwards Air Force Base, CA 93523-5000

Ms. Sandra G. Hart
Ames Research Center
MS 262-3
Moffett Field, CA 94035

Commander, Letterman Army Institute
of Research
ATTN: Medical Research Library
Presidio of San Francisco, CA 94129

Commander
U.S. Army Medical Materiel
Development Activity
Fort Detrick, Frederick, MD 21702-5009

Commander
U.S. Army Aviation Center
Directorate of Combat Developments
Building 507
Fort Rucker, AL 36362

U. S. Army Research Institute
Aviation R&D Activity
ATTN: PERI-IR
Fort Rucker, AL 36362

Commander
U.S. Army Safety Center
Fort Rucker, AL 36362

U.S. Army Aircraft Development
Test Activity
ATTN: STEBG-MP-P
Cairns Army Air Field
Fort Rucker, AL 36362

Commander U.S. Army Medical Research
and Development Command
ATTN: SGRD-PLC (COL Schnakenberg)
Fort Detrick, Frederick, MD 21702

MAJ John Wilson
TRADOC Aviation LO
Embassy of the United States
APO New York 09777

Netherlands Army Liaison Office
Building 602
Fort Rucker, AL 36362

British Army Liaison Office
Building 602
Fort Rucker, AL 36362

Italian Army Liaison Office
Building 602
Fort Rucker, AL 36362

Directorate of Training Development
Building 502
Fort Rucker, AL 36362

Chief
USAHEL/USAAVNC Field Office
P. O. Box 716
Fort Rucker, AL 36362-5349

Commander U.S. Army Aviation Center
and Fort Rucker
ATTN: ATZQ-CG
Fort Rucker, AL 36362

Chief
Test & Evaluation Coordinating Board
Cairns Army Air Field
Fort Rucker, AL 36362

MAJ Terry Newman
Canadian Army Liaison Office
Building 602
Fort Rucker, AL 36362

German Army Liaison Office
Building 602
Fort Rucker, AL 36362

LTC Patrice Cottebrune
French Army Liaison Office
USAAVNC (Building 602)
Fort Rucker, AL 36362-5021

Australian Army Liaison Office
Building 602
Fort Rucker, AL 36362

Dr. Garrison Rapmund
6 Burning Tree Court
Bethesda, MD 20817

Commandant, Royal Air Force
Institute of Aviation Medicine
Farnborough Hampshire GU14 6SZ UK

Commander
U.S. Army Biomedical Research
and Development Laboratory
ATTN: SGRD-UBZ-I
Fort Detrick, Frederick, MD 21702

Defense Technical Information
Cameron Station, Building 5
Alexandra, VA 22304-6145

Commander, U.S. Army Foreign Science
and Technology Center
AIFRTA (Davis)
220 7th Street, NE
Charlottesville, VA 22901-5396

Director,
Applied Technology Laboratory
USARTL-AVSCOM
ATTN: Library, Building 401
Fort Eustis, VA 23604

Commander, U.S. Air Force
Development Test Center
101 West D Avenue, Suite 117
Eglin Air Force Base, FL 32542-5495

Commander, U.S. Army Missile
Command
Redstone Scientific Information Center
ATTN: AMSMI-RD-CS-R
/ILL Documents
Redstone Arsenal, AL 35898

Dr. H. Dix Christensen
Bio-Medical Science Building, Room 753
Post Office Box 26901
Oklahoma City, OK 73190

Director
Army Personnel Research Establishment
Farnborough, Hants GU14 6SZ UK

U.S. Army Research and Technology
Laboratories (AVSCOM)
Propulsion Laboratory MS 302-2
NASA Lewis Research Center
Cleveland, OH 44135

Col. Otto Schramm Filho
c/o Brazilian Army Commission
Office-CEBW
4632 Wisconsin Avenue NW
Washington, DC 20016

Dr. Eugene S. Channing
7985 Schooner Court
Frederick, MD 21701-3273

LTC Gaylord Lindsey (5)
USAMRDC Liaison at Academy
of Health Sciences
ATTN: HSHA-ZAC-F
Fort Sam Houston, TX 78234

Aviation Medicine Clinic
TMC #22, SAAF
Fort Bragg, NC 28305

Dr. A. Kornfield, President
Biosearch Company
3016 Revere Road
Drexel Hill, PA 29026

NVEOD
AMSEL-RD-ASID
(Attn: Trang Bui)
Fort Belvoir, VA 22060

CA Av Med
HQ DAAC
Middle Wallop
Stockbridge Hants S020 8DY UK

Commander and Director
USAE Waterways Experiment Station
ATTN: CEWES-IM-MI-R
Alfrieda S. Clark, CD Dept.
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Mr. Peter Seib
Human Engineering Crew Station
Box 266
Westland Helicopters Limited
Yeovil, Somerset BA202YB UK

Dr. Christine Schlichting
Behavioral Sciences Department
Box 900, NAVUBASE NLON
Groton, CT 06349-5900

COL C. Fred Tyner
U.S. Army Medical Research
& Development Command
SGRD-ZB
Fort Detrick, Frederick, MD 21702-5012

COL John F. Glenn
U.S. Army Medical Research
& Development Command
SGRD-ZC
Fort Detrick, Frederick, MD 21702-5012